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DISEASES OF GRAIN AND THEIR CONTROL

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DISEASES OF GRAIN AND THEIR CONTROL

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Diseases constantly reduce grain crops, with a corresponding reduction in profits to the farmer. The grain grower may or may not be able to recognize them, but he is usually aware of their influence in the reduction of the quantity and quality of his crops. A lack of knowledge of these cereal pests and their control has hindered the farmer in taking the proper steps to reduce and control cereal diseases.

The diseases of grain treated herein include fungus, bacterial, and certain nonparasitic diseases. The crops included are wheat, barley, oats, rye, rice, millets, grain and saccharine sorghums, maize, flax, and sunflowers, all of them crops now grown in California. An index of the diseases according to hosts will be found at the end of the bulletin.

The material to follow is arranged under three classes of information: (1) the description of the disease so that it may be readily identified; (2) sufficient of its life history so that the proper method of control may be applied; and (3) the known control methods.

The sources from which information has been drawn are so numerous and so varied that acknowledgment for each is deemed undesired in a bulletin of this type. The authorship of the figures is given except when originating in our own laboratories.

SMUTS

The commonest and best-known of cereal diseases are the smuts. The life history and control measures relating to smuts are more easily understood than those of many of the other grain diseases.

STINKING SMUT OF WHEAT, OR BUNT

Stinking smut (*Tilletia tritica* and *T. laevis*) attacks wheat (including durum, emmer, spelt, and einkorn) and rye. It can be identified positively by its offensive odor, which is due to trimethylamine, the same substance that causes the odor in rotting fish. No other smut possesses this odor. Bunted plants are usually shorter

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and produce fewer culms or stalks than normal plants. Frequently such short plants are overlooked in the field or the heads escape the cutter bar of the harvester. The spike or head has a swollen appearance, with the galls which replace the kernels pushing out of the enveloping glumes (fig. 1).

Fig. 1.—*A*, Bunted head of Little Club wheat and bunt (*Tilletia tritici*) gall; *B*, disease-free head of Little Club wheat and normal wheat kernel.

The bran or gall covering holds the spores (fig. 3). These spores (chlamydospores) may number from 7 to 9 million per gall, according to the normal size of the kernel. When passed through the threshing machine these dark-colored spores may form a dense smoke-like dust which is carried by the wind to great distances, spreading the infection. Sometimes these spores cause explosions on stationary threshers,

but no explosions on combined harvesters have been recorded in California. The Bates Aspirator, a suction device that may be attached to threshers, prevents this danger by removing much of the spore material from the grain along with many diseased and shriveled seeds.

Fig. 2.—Spores of stinking smut of wheat or bunt clustered on the brush and seed surfaces. Several hundred spores per kernel are required to cause bunt attack. The unbroken seed coats shown here are very resistant to chemical seed injury when liquid solutions are used. *A*, dorsal side; *B*, ventral side.

Bunt spores borne upon the seed (fig. 2) germinate and put forth germ tubes, which establish themselves in the growing points before the seedlings emerge from the soil. The mycelial thread apparently cannot enter the growing point of the young seedling after it rises into the air and is exposed to light. This fact probably accounts for the absence of bunt in volunteer wheat.

The temperatures under which wheat germinates are not always favorable to bunt spores, which germinate best between 48° and 54° Fahrenheit. The moisture requirements of bunt are also more limited than those of wheat; bunt requires from 14 to 32 per cent for best germination. Wheat germinates above and below the temperature and moisture limitations for bunt. Early-sown wheat, for these reasons, may at times escape bunt attack, even though smutty or untreated seed is sown.

Bunt spores from threshers falling upon summer-fallow land may cause smutted crops, even when the seed is treated with chemicals and all seed-borne spores destroyed, because under favorable conditions the spores may germinate and grow in the soil for several weeks. Wheat germinating in such soils may be attacked from soil-borne bunt spores. Against this form of attack only resistant varieties of wheat can afford full protection to the crop.

Intermittent summer rains or heavy fogs foster molds and yeasts, which destroy bunt spores, but in the rainless summers of California these spores lie uninjured until the fall rains occur.

The two species of bunt are distinguished by spore differences. The common bunt of the Pacific Slope, *Tilletia tritici,* has rough (reticulated) spores, while the spores of *Tilletia laevis,* commonly found east of the Rocky Mountains, are smooth (without reticulations) (fig. 3). There are a number of specialized races or physiologic forms of bunt included in these two species. One specialized form of bunt attacks only certain varieties of wheat; other forms attack varieties resistant to the first. These specialized forms appear to maintain their identity. More than one may occur in a single field or area.

While seed treatment is very effective in controlling bunt, it does not prevent attacks from infested soil. Resistant varieties obviate the necessity for seed treatment and definitely prevent smut losses.

Resistant varieties include Hussar, Martin, Albit, and Ridit, which have not been smutted in California. Crosses and back-crosses between these resistant wheats and the standard California varieties have produced wheats like the standard varieties in all practical qualities, but free from smut attack. Australia reports that Florence, Yandilla King, and Nabawa are resistant. Berkeley Rock is resistant in Michigan.

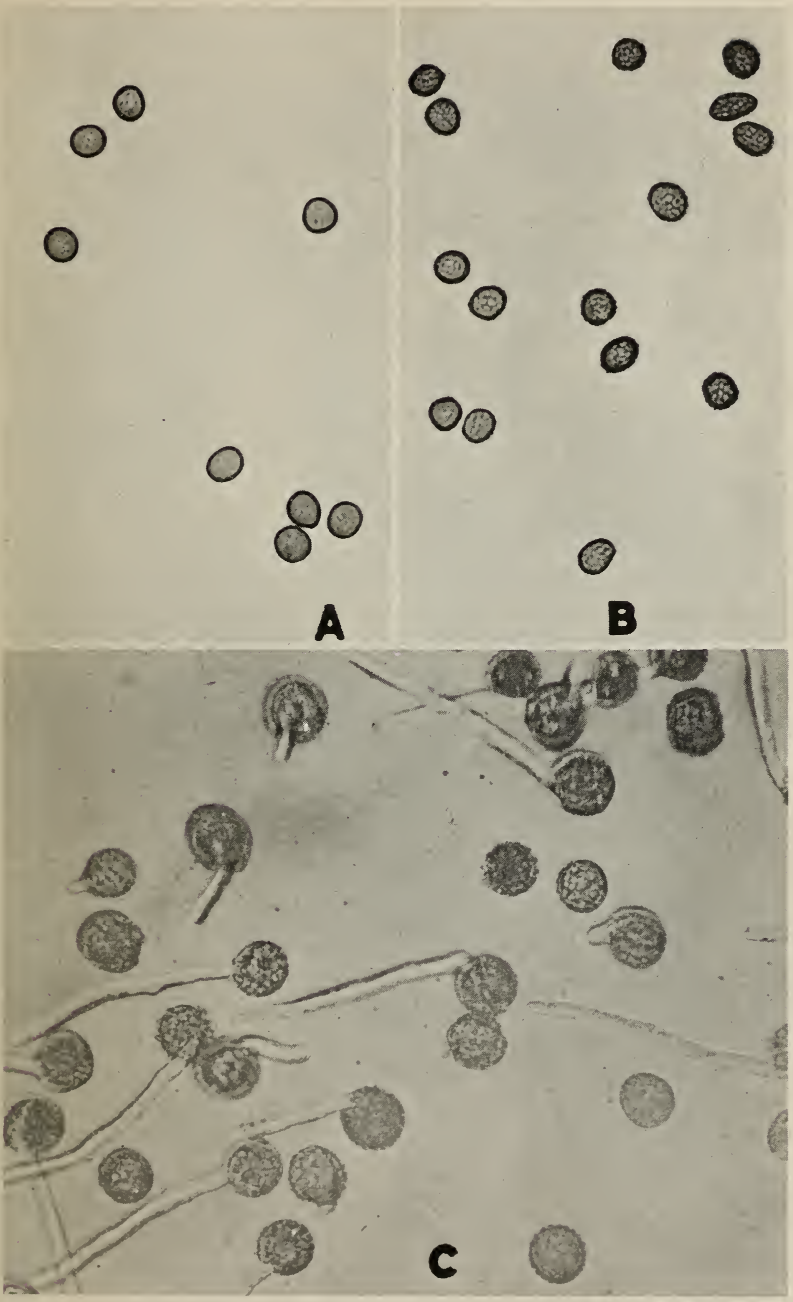

Fig. 3.—*A*, *Tilletia laevis*, smooth-spored bunt; *B*, *T. tritici*, rough, reticulated-spored bunt; *C*, *T. tritici*, with spores germinating.

LOOSE SMUT OF WHEAT

Loose smut of wheat (*Ustilago tritici*) attacks both wheat (fig. 4) and rye. No membrane covers these smut spores, which are soon blown away, leaving the inconspicuous middle stem, or rachis. As the loose smuts form spores (sporulate) at the time the normal plants are blooming, the spores alight upon, or are carried by insects to, the floral parts. There the spores germinate and push the mycelial thread into the germ of the kernel. When the kernel matures and hardens, the fungus goes into a resting stage, awaiting the germination of the kernel. It then grows with the seedling and finally again sporulates when the wheat heads.

Because the disease is carried within the seed, many chemical treatments have little or no effect in destroying this smut. The hot-water treatment (p. 79) is the surest method.

Dry weather, which usually prevails during the flowering period of grain in California, dries out the spores and floral surfaces so that the attacks are rarely completed. For these reasons loose smut becomes important in this state only in the mountainous valleys when spring and summer rains occur or in the foggy coastal belt.

Resistant or immune wheats include Preston, Blackhull, Hussar, Ridit, Forward, Fulcaster, Fultz, Gipsy, Harvest Queen, Leap Purple Straw, Russian, Trumbull, Wyandotte, and White Winter. Only two varieties of rye, Rosen and Rimpau, are known to be susceptible.

FLAG SMUT OF WHEAT

Flag smut (*Urocystis tritici*) attacks mainly the leaf blades and sheaths (fig. 5), but may occur on the stem and head. Usually no heads are formed, and consequently no grain is produced, by diseased plants. The leaves are finally split by spore eruptions along the parallel veins, causing the leaf to fray into strips. The spores (fig. 6 *C*) may be carried to the next crop on the seed. For seed-borne spores copper carbonate is reported to be less effective than other standard disinfectants like blustone (p. 80), formaldehyde (p. 79), and mercuric organic compounds. The spores carried by the infested straw, however, live in the straw and soil for over a year and, when buried or plowed under, may survive to infest the next crop. Summer-fallow, where the straw is completely rotted during the first winter months, may eliminate the disease. Otherwise rotations with some other cereal or other crop should be practiced.

Fig. 4.—Loose smut of wheat (*Ustilago tritici*) on wheat. *A*, normal head of club wheat; *B*, head smutty before heading; *C*, spores beginning to blow away; *D*, spores almost blown away; *E*, spores entirely blown away.

Immune or highly resistant varieties include China, Forward, Fulcaster, Fulkio, Gladden, Mammoth Red, Portage, Red Rock, Rudy, Shepherd, and Galgalos.

Flag smut is very destructive in Australia, from whence it was probably introduced into the Mississippi Valley during the World War. It also occurs in China where climatic conditions closely resemble those of California. Any appearance of this disease should be reported at once.

Fig. 5.—Flag smut of wheat (*Urocystis tritici*); *A*, normal healthy leaf; *B* and *C*, smutted leaves.

STEM SMUT OF RYE

Stem smut of rye (*Urocystis occulta*), shown in *A* and *B* of figure 6, is similar in all respects to flag smut of wheat (fig. 6*C*), except that it does not attack any host but rye. Preventive measures are the same, namely, dusting the seed with copper carbonate (p. 81) and practicing summer fallow and crop rotation. No resistant varieties are known.

Fig. 6.—*A*, stem smut of rye (*Urocystis occulta*); *B*, germinating spores of stem smut of rye; *C*, germinating spores of flag smut of wheat. (After McAlpine.)

Fig. 7.—Covered smut of barley (*Ustilago hordei*).

COVERED SMUT OF BARLEY

Covered smut of barley (*Ustilago hordei*) attacks no other host plant. The attacked head, or spike (fig. 7) is converted into a mass of spores or galls each covered with a thin white membrane, which is finally blown away. The diseased head is dark olive-brown in color. The spores are smooth as contrasted with the rough spores of naked smut of barley (fig. 3).

Infection by covered smut of barley is accomplished by spores on the seed. No soil infestation is known to occur. Seed treatment, when effective, eradicates covered smut. Copper-carbonate dust treatments (p. 81) usually do not immediately give adequate control of the attack, as they do with bunt in wheat; this is due, no doubt, to the heavy rough seed coat of the barley kernel. However, thorough and repeated dusting every year appears to eliminate this smut satisfactorily. Some of the organic mercuric dusts (p. 80) and formaldehyde dusts (p. 79) are very effective.

Several physiologic forms of covered smut have been found, so that varietal resistance or immunity may not always hold. The known resistant and immune varieties include California Mariout, Sacramento, and Kamaninzi.

Covered smut is readily affected by unfavorable weather conditions, so that its occurrence is erratic. In certain years badly smutted seed will result in little or no smut, while in other years seed so slightly smutted as to appear clean will yield a very smutty crop. Barley seed should be treated every year with copper-carbonate dust (p. 81).

LOOSE SMUT OF BARLEY

Loose smut of barley (*Ustilago nuda*) attacks no other host. In contrast with covered smut of barley, the attacked head, or spike, is not enveloped in a white membrane. All the awns, or beards, are reduced to fine threads and the whole mass of spores is soon blown away, leaving the central stem, or rachis, as with loose smut of wheat (fig. 4).

The spores mature as the normal plants bloom and, falling upon the floral parts, germinate and enter the growing kernel. No smut injury is apparent, but when the seed is sown, the resulting plant is infected and yields no grain. As with the similar disease, loose smut of wheat, the hot-water treatment (p. 79) is the most certain remedy, although organic mercuric dusts (p. 82) are said also to control the disease.

Loose smut of barley is much more common in California than loose smut of wheat, owing no doubt to the greater resistance of the spores to heat and drought. In the coastal areas it frequently causes considerable damage. Only one variety, Nakano Wase, has been found to be immune, but Manchuria, Minnesota 184, and Featherstone are very resistant.

HIDDEN SMUT OF OATS AND LOOSE SMUT OF OATS

Since hidden smut of oats (*Ustilago laevis*) and loose smut of oats (*Ustilago avenae*) are similar in many respects and usually yield to the same seed treatments, they are described together. The smutted head, or panicle, attacked by hidden smut is covered with a whitish membrane resulting from the diseased glumes, while the head attacked by loose smut exposes the black spore-masses more prominently. Wind shattering sometimes renders identification by head observation difficult. The spores, however, make identification certain, for those of hidden or covered smut are entirely smooth, while those of loose smut are rough (minutely echinulate); they show much the same difference as that between *Tilletia laevis* and *T. tritici* (fig. 3).

Infection of the seed occurs largely in the unharvested grain during the flowering period, but may also become infected from spores carried on the seed coat. Both smuts hibernate inside the seed germ and again grow with the germination of the seed and penetrate the very young oat seedling. The fungus then continues through the host.

Seed treatment is very effective for its control. There appears to be no attack from infected soil. Formaldehyde, especially Haskell's dry method (p. 80) and formaldehyde dust (p. 80), have given good control without serious injury to seed. Copper carbonate is less effective than the other treatments because it does not destroy the disease when borne internally, but is less expensive and causes no seed injury, so that better yields are secured in spite of slightly more smut. When continued year after year, the effect of copper carbonate (with 50 per cent copper; see p. 81) is remarkably efficient in reducing smut losses.

Markton, Golden Giant, and Black Tuesday are immune, and Joanette, Kanota, Burt, and Fulghum are highly resistant to all strains of smuts in California; California Red is fairly resistant. Some varieties of oats are resistant to one smut and not the other. A more virulent physiologic form of covered smut has appeared in the Mississippi Valley which attacks Kanota, Fulghum, and California Red, and it appears to have gained entrance into California. There are apparently a number of physiologic forms of these smuts, but fortunately for breeding purposes, there are varieties resistant to them.

KERNEL SMUT OF SORGHUM

Kernel smut of sorghum (*Sphacelotheca sorghi*) attacks sweet and grain sorghums (fig. 8 *A*), broom corn, Sudan Grass (fig. 8 *B*), and millets. The smutted head, or panicle, appears grayish in color owing

Fig. 8.—Kernel smut (*Sphacelotheca sorghi*); *A*, on Sudan grass; *B*, on honey sorghum.

to the white membranous covering of the gall, or smutted seed. These galls are usually swollen to two or three times the normal size of the seed. Some seed may occasionally be found in a smutted head.

Kernel smut is entirely seed-borne, so that seed-treatment controls it. Copper-carbonate dust (p. 81) readily controls and prevents it.

The spores of kernel smut are spherical or subspherical, thick-walled, smooth, and olive-brown in color.

Kernel smut is the commonest smut of sorghum. Physiologic forms are known, as illustrated by the sudden susceptibility of Dwarf milo, formerly immune to kernel smut.

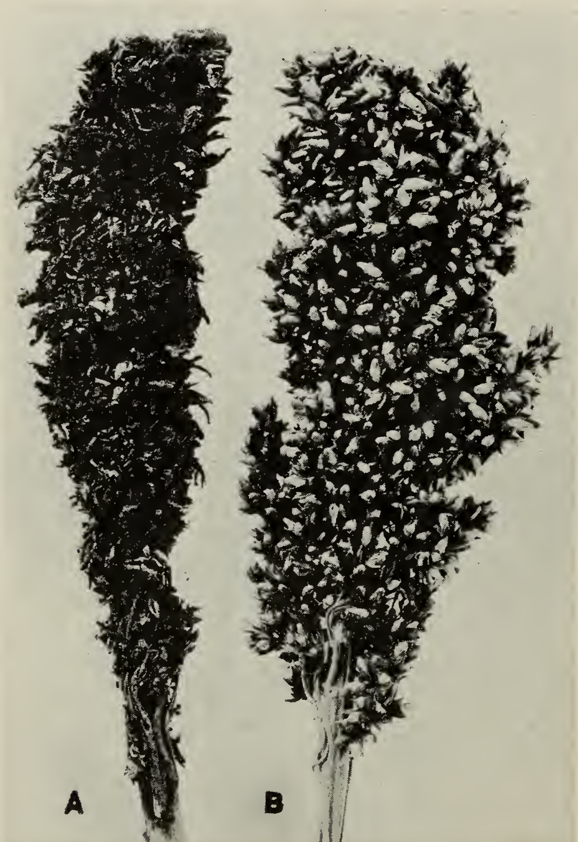

Fig. 9.—*A*, loose smut of sorghum (*Sphacelotheca cruenta*); *B*, kernel smut of sorghum (*S. sorghi*).

Resistance to kernel smut has been summarized as follows: Shallu is very susceptible; sweet or saccharine sorghums are highly susceptible; Sudan grass is only moderately susceptible (fig. 9 *B*); the three varieties of broom corn are moderately susceptible; among the kaoliangs, Shantung is very resistant, but the other varieties vary in susceptibility; the kafirs are all susceptible; the durras, White and Brown, are susceptible, but some new strains of White durra are

highly resistant; all milos possess marked resistance; feterita is very resistant and White Yolo and Dwarf Hegari are also highly resistant. All new varieties introduced into a region should be carefully dusted with copper carbonate to prevent kernel smut in any of its physiologic forms.

Fig. 10.—Head smut (*Sorosporium reilianum*) on maize; *A*, smutted tassel; *B*, smutted ear.

LOOSE SMUT OF SORGHUM

Loose smut of sorghum (*Sphacelotheca cruenta*) usually attacks the same varieties as the kernel smut (p. 15) and under the same conditions of temperature and soil moisture. The head of sorghum attacked by loose smut lacks the gray membrane-covering of the gall (fig. 9 *A*). Usually all the spikelets are smutted. This condition permits the smut spores to be blown away by the wind. Fewer spores are thus carried to the thresher, which may account for the very infrequent occurrence of this smut compared with kernel smut.

It is difficult to distinguish the spores of these two smuts, but the spores of the loose smut are somewhat larger, more irregular in shape, with a slight pitting in the wall which is absent in the kernel smut.

Seedling infection from spores borne on the seed appears to be the only means of infection. This smut is therefore controlled by treating the seed with copper-carbonate dust (p. 81) in the same manner as for kernel smut.

Fig. 11.—Head smut (*Sorosporium reilianum*); *A*, on sorghum; *B*, on maize.

HEAD SMUT OF SORGHUM AND MAIZE

Head smut (*Sorosporium reilianum*) attacks both sorghum (fig. 11) and maize (fig. 10), but each host appears to have its own physiologic form which does not readily attack the other. The whole plant

and head or ear are stunted to about two-thirds normal size and usually no seed is produced. In maize the tassel is also attacked. Smutted sorghum plants may send out head shoots from the lower nodes or joints but these also are either wholly smutted or infertile. The whole head or ear becomes stringy and is much condensed. The smut masses are inclosed in a pinkish-white membrane which soon becomes ruptured, discharging the dark-brown spores into the air.

At first the spores unite in the form of balls, but later separate. The spores are somewhat angular and minutely but densely covered with wart-like excrescences. The spores germinate readily in rain or soil water and usually make their heaviest attack from the soil.

At Davis and elsewhere in California this disease has been brought in with seed from China and Texas, after which it spread where the hosts are grown continuously. When other crops are grown for some years to the exclusion of the host, the disease entirely disappears.

The damaged plants usually comprise a small percentage of the whole (0.5 to 3.0 per cent) but the attack may reach 30 per cent or more in both maize and sorghum.

The sweet, or saccharine sorghums are most susceptible, followed by kaoliang and kafir. Milos, broom corn, and durras have been free from attack in California. All varieties of maize appear subject to attack. Breeding for resistant saccharine sorghums appears possible because some grain sorghums seem immune.

Seed treatment (copper carbonate, p. 81) is recommended for all saccharine sorghum seed brought into an area for the first time, especially with Honey and Orange sorghums, which are very susceptible.

LONG SMUT

Long smut (*Tolyposporium filiferum*) is found in Asia and Africa on the sorghum group but has not been found in America. Only a few flowers of the head are attacked. These kernels are replaced by long curved cylindrical galls, which are about twice as long and thick as the galls of kernel smut (fig. 8). The spores are grouped in balls, which readily distinguish this species from the kernel smuts. The spores are rough like those of *Tilletia tritici* (fig. 3 *B*).

It is not definitely known how the disease is carried, but seed treatments appear to have no effect. Varietal resistance is unknown. Sorghum seed from Asia and Africa should be carefully treated by the hot-water method (p. 79).

BOIL SMUT OF MAIZE

Boil smut (*Ustilago zeae*) attacks maize only, but all varieties of maize are susceptible. All aerial portions of the plant are attacked. The sporulating stage appears in the form of great boil-like excrescences, often several inches in length and thickness (fig. 12). The boil, or mass, is covered with a whitish membrane which bursts on drying. The smut on the ears gives the farmer the most concern, for the kernels are wholly or in part destroyed. Fusarium and other fungus rots frequently follow the smut, causing further injury.

Fig. 12.—Boil smut (*Ustilago zeae*). (From Illinois Agr. Exp. Sta. Bul. 225.)

The smut spores are oval (ellipsoid) in shape and rough (bluntly echinulate). The spores (chlamydospores) may remain viable for two or three years. They germinate on manure and corn refuse and produce other spores (conidia) which are then carried in the air to the corn where they grow and penetrate the epidermis of the host when the plants have reached a height of 2 feet or more.

As the infection is never found on the young seedling, it is not probable that the seed carries the disease. Seed treatment has proved useless in reducing the smut. Destroying all diseased plants as soon as they appear and removing all contaminated refuse might reduce boil smut, but this is not practical. Unless the boils attack the ear, little damage seems to follow except in cases where barren stalks result. Maize in dry areas is more subject to boil-smut attack than in

areas where the air is more humid. Many physiologic forms of this smut are known.

Resistance in selfed lines of maize has been found and several investigators have been able to secure highly resistant strains. (Selfing is accomplished by hand-pollinating an ear with tassels from the same

Fig. 13.—Proso smut (*Ustilago panici-miliacei*); *A*, smutted panicle; *B*, normal panicle.

plant.) It appears to be possible to do this with most varieties, enabling the plant breeder to select smut-resistant strains from the variety best adapted locally.

PROSO SMUT

Proso smut (*Ustilago panici-miliacei*) attacks proso millets only Proso millet (*Panicum miliaceum*) is also known as hog, or broomcorn millet. The whole head, or panicle, is reduced by the smut and

covered with a thin white membrane (fig. 13) which ruptures on drying, scattering the spores to the seeds which then carry the infection.

The spores are reddish-brown in color, oval (ovoid to subspherical), regular, and smooth. On germination the spores send out germ tubes which penetrate the tender tissue of the seedling and enter the growing point. The fungus is propagated only by spores on the seed, so that treatment with copper carbonate (p. 81) controls it effectively.

FOXTAIL MILLET SMUT

Foxtail millets attacked by smut (*Ustilago crameri*) are included in the species of the genus *Chaetochloa* (*Setaria*). The common varieties listed are German, Kursk, Goldmine, Hungarian, and Siberian. Foxtail millet smut forms a separate gall from each seed. It appears to be seed-borne only. The germ tube penetrates the growing point of the millet seedling either directly or by means of mycelium from secondary conidia. The spores are long-lived and are known to be highly viable after three years. They are dark olive in color, very irregular in form and smooth or very finely reticulated (fig. 3).

As this smut is seed-borne, copper carbonate (p. 81) or formaldehyde (p. 79) gives excellent control. There are no known resistant or immune varieties of foxtail millet.

BLACK SMUT OF RICE

Black smut of rice (*Tilletia horrida*) occurs in Arkansas, Louisiana, and adjacent rice areas, and in oriental countries, but has not appeared in California.

It appears probable that the fungus gains entrance into the seed by way of the floral parts at blooming time. The diseased kernel finally becomes a mass of black spores.

The selection of uncontaminated seed will stamp it out where no volunteer rice is grown. For infected seed the hot-water method (p. 79) is the most efficient, but organic mercuric compounds are suggested as alternative methods (p. 82). No immune varieties are known, but Japanese varieties appear to be fairly resistant. Honduras types and red rice are most readily attacked.

GREEN SMUT OF RICE

Green smut of rice (*Ustilaginoides virens*) is widespread, especially in the oriental countries. In Louisiana this fungus occurs, but is not common.

Only a few of the kernels on the panicle are attacked. The diseased kernel becomes a horny body called a sclerotium. This greenish ball may reach ¼ inch in diameter. The spores (conidia), green in color, spherical and rough-walled (echinulate) are borne on the surface of the ball (sclerotium), which is so large that it can readily be separated from the rice seed by cleaning machinery.

SOOTY MOLD

Sooty mold (*Hormodendrum cladosporioides* or *Cladosporium herbarum*) attacks wheat, barley, oats, rye, maize, sorghum and rice but causes no marked damage in California except on wheat. The fungus requires moist atmospheric conditions for its spread, and for this reason it seldom causes serious injury away from the coastal areas. It usually goes inland as far as Riverside and may occasionally injure wheat crops at Stockton. In the Monterey Bay region and similar areas, profitable wheat cropping is impossible because of its constant attacks. Here the farmers call it black rust, because of the blackened heads. The spores are carried by the wind from trees and shrubs, on which the fungus is commonly found throughout the year.

The fungus (mycelial) threads creep over the leaf surfaces and heads and send up branches bearing globose dark-olive-colored spores (conidia). These dark spores rub off readily, giving the effect of smut. The spores are smooth and linked together and are readily distinguished under the microscope from spores of bunt or other smuts of wheat and barley, with which grain buyers have at times confused them.

When the heads begin to store starch, the sooty mold attack becomes severe and frequently prevents any of the grain from filling normally. If the head is covered by a paper bag when it emerges from the sheath, so that the wind is excluded, the fungus does not attack and the head will fill normally. The plants and kernels are never entirely destroyed, but the grain may be badly shriveled.

Securing resistant varieties offers the best control. No highly resistant wheats among the common varieties are known but certain resistant hybrid wheats are promising.

ERGOT

Ergot (*Claviceps purpurea*) attacks rye (fig. 14), wheat, and barley among the cereals, and several grasses. In California, ergot has been found only on rye grass (*Lolium perenne*) and wild rye (*Elymus glaucus, E. condensatus,* and *E. triticoides*). Several physiologic forms of ergot have been found, but in California the forms attacking cereals have not yet appeared. The climatic conditions appear to favor the disease, for it is found plentifully in its grass hosts, not only in the moist coastal areas, but in all the hot interior valleys and in the mountainous valleys of the northern regions of the state.

Fig. 14.—Ergot of rye; *A*, the ergots, or sclerotia, three to four times the size of the rye kernel; *B*, kernels of rye. (After U. S. Dept. Agr. Cereal Disease Investigations.)

Only a few of the florets in the head or spike of the grain or grass are attacked, and all of these do not result in ergots. The ergots (sclerotia) develop from the fungus threads (mycelium) in the diseased florets and appear as horny, long, cylindrical black bodies several times the length of the seed of the host. The disease enters the host at blossoming time by means of insects or wind. These spores occur in a sticky honey exudate, found in the diseased head and very attractive to insects. The spores on reaching the new flowers, ger-

minate and penetrate the embryo of the growing seed, giving rise to a mass of fungus threads which form the thick hard purplish body called the ergot (sclerotium). The ergot drops to the ground or is harvested and sown with the seed. From the ergots grow tiny mushrooms about the size of an ordinary pin. These mushrooms fruit (sporulate) and the spores are again carried by insects to new hosts.

Ergotism in cattle, horses, and other animals causes poor blood circulation and abortion. It is especially severe in cattle. The poison accumulates slowly and there is no known antidote.

Ergots live over for at least one year in the soil so that clean culture or rotation is necessary to eradicate it from infested fields. To remove the ergots from seed the salt-water method is used (p. 81).

RUSTS OF GRAIN CROPS

Rusts are perhaps the most destructive of cereal diseases, at least when in epidemic form. The rusts are very diverse in form and occur in widely different host plants.

Stem-rust epidemics depend upon favorable temperature and humidity of the air and moisture of the soil. There must be abundant dews or morning fogs followed by bright weather for the rest of the day. Abundant rain (usually over 2 inches) or high humidity or plentiful irrigation water is required during the tillering and heading season to produce heavy rust attack. If the temperature holds below 60° F while the grain is maturing, little or no stem rust develops, but average temperatures between 66° and 72° F are favorable to rust epidemics. Drying north winds may halt a rust epidemic when the grain is in head.

The resting stage of stem rust is found in the black spores (teliospores) shown in figure 15*t*, which are the last to appear on the infested wheat plant. These spores germinate and attack the barberry bush or alternate host. Alternate hosts are plants other than those of the grass family which carry one or more stages of the rust. A list of the alternate hosts of the common cereal rusts is given in table 1. Two kinds of spores are produced in succession on the barberry, the first found in the upper surface of the leaves and the second on the underside, giving rise to the cluster-cup stage. Spores from these cluster cups then pass to the wheat or other grain or grasses to form the common red-spore stage (uredinial) shown in figure 15 *u*.

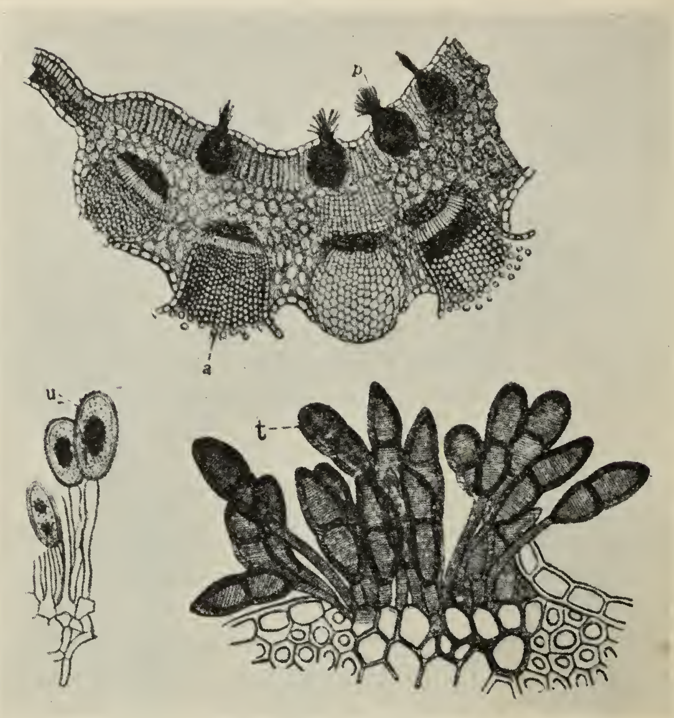

Fig. 15.—Spore forms of stem rust (*Puccinia graminis*); *p*, pycnidia on the upper side of the barberry leaf, giving rise to the sexual phase; *a*, aecia on the lower side of the barberry leaf bearing aecial spores, which attack cereals; *u*, urediniospores (red) causing red rust on cereals; *t*, teliospores, black rust stage, which carry the rust to the barberry, completing the cycle. (After De Bary.)

TABLE 1

ALTERNATE HOSTS OF CEREAL RUSTS

Rust		Host	Alternate host
Common name	Botanical name		
Stem rust	*Puccinia graminis tritici*	Wheat	Barberry (*Berberis vulgaris* and *Mahonia* sp.)
Stem rust	*Puccinia graminis avenae*	Oats	Barberry (*Berberis vulgaris* and *Mahonia* spp.)
Stem rust	*Puccinia graminis secalis*	Rye	Barberry (*Berberis vulgaris* and *Mahonia* spp.)
Leaf rust	*Puccinia triticina*	Wheat	*Thalictrum* spp., *Nonea rosea*
Leaf rust	*Puccinia anomala*	Barley	*Ornithogalum umbellatum*
Leaf rust	*Puccinia dispersa*	Rye	*Anchusa* spp., *Nonea rosea*
Crown rust	*Puccinia coronata*	Oats	*Rhamus cathartica*, *R. caroliniana*
Stripe rust	*Puccinia glumarum*	Wheat, barley, and rye	Unknown
Leaf rust	*Puccinia purpurea*	Sorghum	Unknown
Leaf rust	*Puccinia sorghi*	Maize	*Oxalis stricta*
Leaf rust	*Puccinia helianthi*	Sunflower	*Helianthus annuus*
Flax rust	*Melams pora lini*	Flax	Unknown

In addition to the alternate hosts—usually plants widely different from the cereal host—a large number of grasses carry the red rust, or common stage, so that constant sources of infestation are available. The red-rust stage may continue the rust indefinitely without any of the other stages, and does so where no barberry infestation occurs. As barberries and other alternate hosts of cereals rust do not carry the disease in California, probably because of the usual dry sunny weather at this period, only the red-rust stage need be considered. The mild climate of the state permits the red-rust stage to exist throughout the year on grass hosts or volunteer grains. These red spores are carried hundreds of miles by the wind.

Fig. 16.—Aeroplane dusting a wheat field with sulfur to control stem rust. Three applications beginning at the flowering period offer good protection. (After Bailey and Greavey, 1928.)

Control of the cereal rusts by seed treatment is impractical because the spores are not borne on the seed. Recently, however, Canadian fields have been dusted with sulfur dusts. Three applications, made by means of an aeroplane, beginning at flowering time, are reported as successful (fig. 16).

Breeding for rust-resistant varieties is complicated by the presence of physiologic forms. It is necessary to secure resistance to all of the prevailing forms before a variety of grain is safe from rust attack. Much progress has been made along these lines, and eventually cereal rusts may be controlled by breeding resistant varieties adapted to each large grain area.

The red spores of stem rust (on wheat, barley, rye, and oats) contain four spore pores, or germ openings, found in the midsection. In leaf rust of wheat the spore pores (fig. 17) may reach nine or ten in number and are scattered irregularly over the spore.

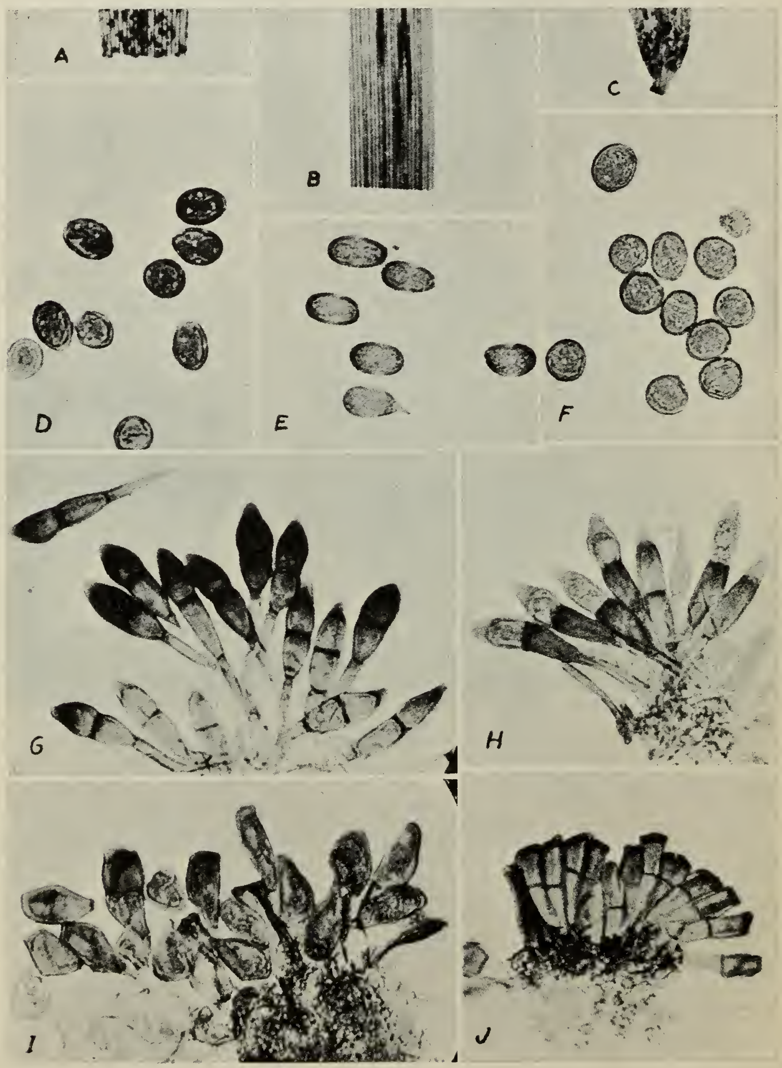

Fig. 17.—*A, B, C,* Telia bearing black spores; *D, E, F,* uredinospores (red spores) showing spore pores; *G, H, I, J,* forms of teliospores (black spores). (After McAlpine.)

If the spores are placed on a glass, by treating the spores with gentian-violet (1 per cent solution) for 2 to 5 minutes, clearing with

alcohol until the pores show well, and following with oil of cloves solution, the pores may be readily seen and counted. If the spores have been germinated, the contents of the spore will largely disappear, rendering the pore count easy.

Crown rust of oats (fig. 20) is identified by the crown-like corrugations on the upper section of the black spore (teliospore).

Fig. 18.—*A*, Kanota K 5179, very susceptible to stem rust, but resistant to leaf rust; *B*, Richland 320*a*, immune to stem rust in California.

STEM RUST OF WHEAT

Stem rust of wheat (*Puccinia graminis tritici*) does not attack oats or rye but is known to attack barley. It also is found on a large number of grasses. The alternate host, the barberry, however, is not attacked naturally by stem rust in California.

Stem rust appears in epidemic proportions at the time the grain is in head. It attacks the leaf sheaths enclosing the stem, hence it is

called stem rust. The pustules are long, dark red in color, and when erupting curve back the edges in ragged margins. The head attack is particularly destructive. The wheat plant, when badly attacked, is unable to nourish both the fungus and itself and may die outright before the grain is properly developed.

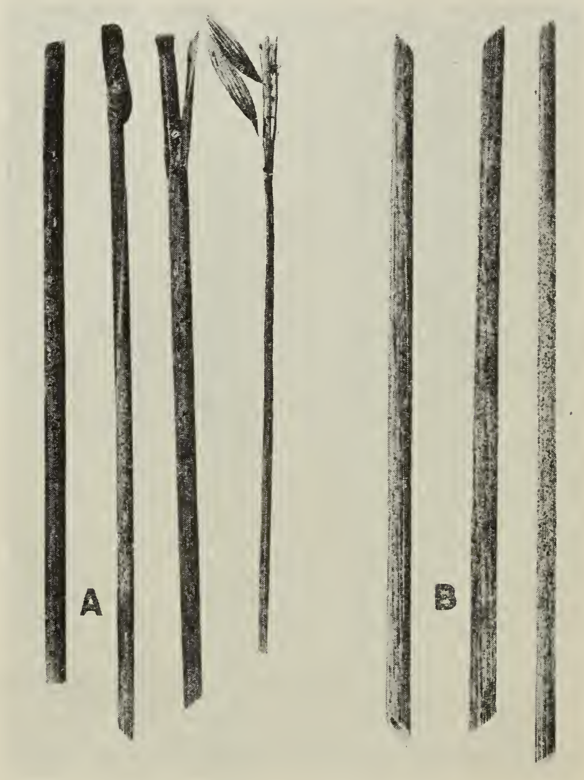

Fig. 19.—*A*, Long's White tartar C 1026; *B*, White Tartar C 1020. The small sori or pustules indicate resistance to stem rust (*Puccinia graminis avenae*).

Several physiologic forms are known to exist in California. A number of very resistant varieties are known, but many of these are wheats not suited for bread-making, namely, emmers, durums, and poulards. A few very resistant bread-wheat varieties include Webster, Kanred, Hope, Defiance, and a number of wheat hybrids produced in California.

OAT STEM RUST

Oat stem rust (*Puccinia graminis avenae*) (fig. 18) causes a great deal of damage in the state. The life history and alternate host are

the same as for wheat and, like stem rust of wheat, it has a number of physiologic forms, although only one has been found in California. This is fortunate in breeding for resistant varieties. The varieties resistant to oat stem rust include Richland (fig. 18 *B*) (immune in California), White Russian, Green Russian, Long's White Tartar, White Tartar, Rurakura, Edkin, Anthony, and Iogold (fig. 19).[2] A number of highly resistant hybrids between Kanota, the standard variety of the state, and Richland have been created by the writer, which should answer the stem rust problem for California.

STEM RUST OF BARLEY

Barley is so seldom injured by stem rust (*Puccinia graminis*) that it is used to replace wheat where stem rust is a limiting factor in wheat production. Stem rust, however, occasionally attacks and injures barley. The life history of barley stem rust is the same as that of wheat stem rust. No varietal resistance has been determined for barley because of the infrequency of stem-rust attack upon it. Lion is reported to be a highly resistant variety.

STEM RUST OF RYE

Stem rust of rye (*Puccinia graminis secalis*), which is similar in its life history to wheat stem rusts, is as rare in California as stem rust of barley, and need give the farmer no especial concern. There is, however, evidence of physiologic forms in rye. At the Minnesota Experiment Station, certain isolated strains were found to be highly resistant to stem rust.

LEAF RUST OF WHEAT

Leaf rust of wheat (*Puccinia triticina*) is usually present in the state but rarely assumes the proportions of an epidemic. It appears much earlier than the stem rust, which may also be present on the same plant.

The pustules (sori, or uredinia) are small and oval in form, usually very numerous, and of a bright brick-red color. Only when these pustules fuse do they resemble those of stem rust, which are longer and darker in color. The rust attack on the leaves weakens the plants, inducing lodging. The grain may be badly shriveled in certain spots in the fields. Leaf rust of wheat is carried entirely in the red-spore stage. There appear to be few varieties resistant to all of the several physiologic forms known to exist. The known resistant wheats include Kanred, Fulcaster, and Malakoff.

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[2] Mackie, W. W. Oat varieties in California. California Agr. Exp. Sta Bul. 467:1–46. 1929.

CROWN RUST OF OATS

Crown or leaf rust of oats (*Puccinia coronata*) attacks only oats (figs. 20 and 43, *B* and *C*) among the cereals, but has a number of grass hosts. The alternate host, buckthorn (*Rhamnus* spp.) does not here carry the rust. This rust at times causes considerable damage but is over-shadowed by the more destructive stem rust (fig. 18).

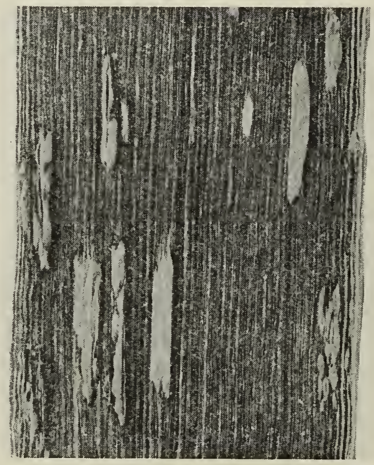

Fig. 20.—Crown rust of oats (*Puccinia coronata*). The pustules (uredinia) are held in shape by tough skin (epidermis) coating. Contrast this with stem rust (fig. 18).

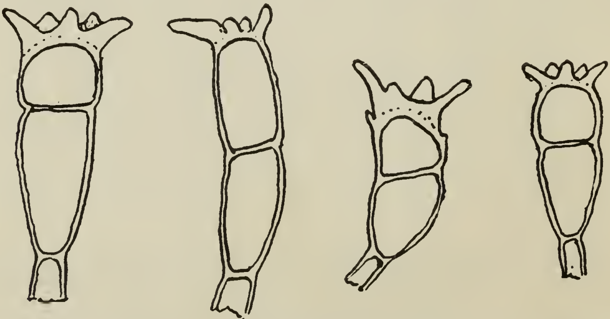

Fig. 21.—Forms of black spores (teliospores) of crown rust (*Puccinia coronata*). (After Bolley.)

The pustules of crown rust, found mainly on the leaves, are small, and usually erupt slowly. The lighter red color of the spores and the glazed-over appearance of the pustule cover are used to distinguish crown rust (fig. 20) from the leaf rusts of other cereals. A number of physiologic forms have been found, but only one is known to exist in California.

The common oat of the state, California Red, is very resistant to crown rust, as is Kanota, another popular variety. Other resistant varieties are Appler, Burt, Golden Rustproof, Green Mountain, Red Rustproof, Iowar, and Rurakura.

LEAF RUST OF BARLEY

Leaf rust of barley (*Puccinia anomala*) may assume epidemic proportions, especially in the coast and Sacramento Valley regions, where it is also found on wild barley (*Hordeum murinum, H. nodosum*, etc.). The pustules are very small and light red in color and may almost completely cover the leaf surface. This rust appears earlier than the other cereals rusts. When the black-spore stage arrives, the pustules may show blanched circular areas about them, with margins full of black spores (teleutospores). The alternate host, which does not occur in California, is *Ornithogalum umbellatum*. Highly resistant varieties are known but none possess outstanding useful or agronomic characters.

LEAF RUST OF RYE

Leaf rust of rye (*Puccinia dispersa*) is rare in California and causes no appreciable damage. It closely resembles leaf rust of wheat. Its alternate hosts are *Anchusa* spp. and *Nonea rosea,* which do not occur naturally in California. It also has a number of grass hosts. A number of resistant strains have been found in Abruzzes rye which are self fertile and persistent (that is, the resistance is maintained).

STRIPE RUST

Stripe rust (*Puccinia glumarum*) attacks wheat (fig. 22) and to a smaller extent, spelt, emmer, barley, and rye. A large number of grasses are also its hosts. An alternate host has not been found. In England and Scandinavia and certain parts of Mexico, stripe rust frequently causes immense damage to wheat crops, but in California the injury caused by it is slight and of rare occurrence. A field thoroughly infected may produce well-filled grain because the stripe rust may suddenly be arrested by heat while the grain matures naturally.

The pustules (sori) are small, but are usually confined between the parallel veins of the leaf. Many pustules unite end to end and form long yellow stripes, characteristic of this rust.

The older varieties of wheat grown in California, including White Australian, Sonora, and Little Club, are but slightly affected, while the newer varieties like Bunyip, Hard Federation, White Federation, Federation, and Baart are very susceptible. A number of highly resistant varieties are known, including Barletta, Kinney, Rink, Royalton, Challenge, and White Winter.

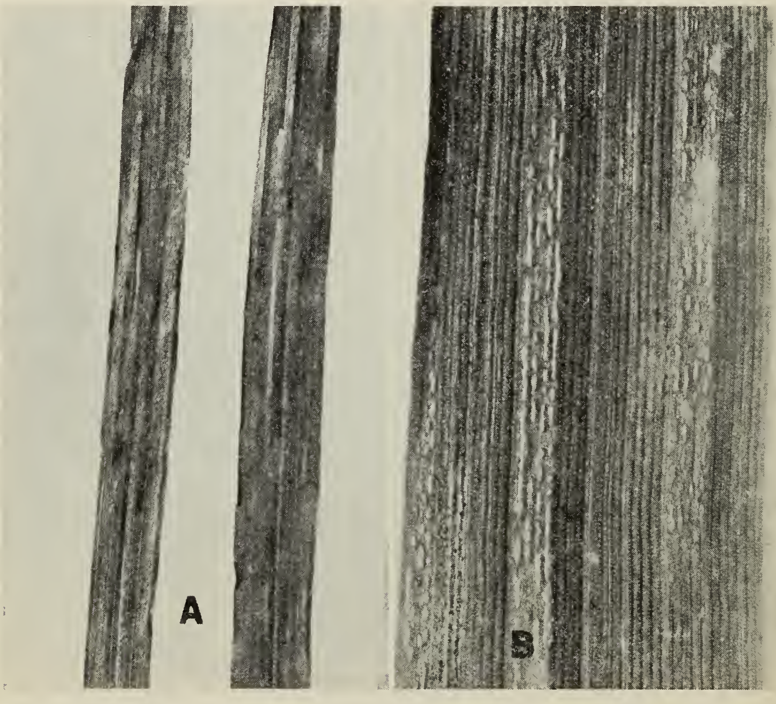

Fig. 22.—Stripe rust of wheat (*Puccinia glumarum*); *A*, red pustules (uredinia or sori) of summer spores together with black pustules (telia) of winter spores; *B*, normal stripe of rust confined between parallel ribs.

MAIZE RUST

Maize rust (*Puccinia sorghi*) is rather rare in California but on occasions may cause considerable damage. It apparently attacks no other host. The rather long pustules, closely resembling those of stem rust on wheat, are borne on the leaves. The spores are globose and slightly rough. Sorrel (*Oxalis*) is the alternate host.

A number of physiologic forms have been found. Resistant varieties include Golden Glow, Golden Bantam, and Howling Mob. Breeding for resistance in local varieties is possible by selfing and selection of resistant strains.

SORGHUM RUST

Sorghum rust (*Puccinia purpurea*) may attack any of the sorghum group, including Sudan grass and Johnson grass, but the damage is not economically important. The affected leaves are purple-spotted and the pustules are irregular, small, and dark brown, bearing smooth, dark-brown spores. The milo varieties of grain sorghum are all very resistant, Dwarf kaoliang and Shallu considerably resistant, and Blackhull and Reed kafir moderately resistant. All sweet sorghums are susceptible.

RICE RUST

Rice rust (*Puccinia oryzae*) attacks only rice and is similar in habit to other leaf rusts of cereals. Serious damage to rice crops has been reported in Europe. As with other cereal rusts, the securing of resistant varieties is the best remedy.

SUNFLOWER RUST

Sunflower rust (*Puccinia helianthi*) attacks several wild species of sunflowers and all cultivated forms. The rust was introduced from Europe. All forms of the rust grow on the sunflower; it has no alternate host. It has undoubtedly several physiologic forms. As the sunflower must of necessity outcross, it is difficult to secure resistant varieties and none have yet been developed.

FLAX RUST

The flax crop is frequently badly damaged by flax rust (*Melampsora lini*). It thrives best at temperatures about 80° F. Sulfur dust would no doubt reduce the disease but on account of the long period over which the several rust forms may attack it, would undoubtedly be too costly.

Breeding and selection for resistant varieties has been very successful, but out-crossing, which is quite common, renders constant selection necessary if resistant varieties are to be maintained. At the Minnesota Agricultural Experiment Station highly resistant selections of Winnoa and Chippewa have been found.

HELMINTHOSPORIUM DISEASES OF CEREALS

Helminthosporium diseases occur on cereals and closely related grasses. They are usually manifest in characteristic lesions on the leaves, although the roots and heads may be attacked. Some of these

diseases may produce several generations during the growing period of the plant—for example, net blotch (*Helminthosporium teres*)—or only one generation during the life of the host, as with stripe disease of barley (*H. gramineum*). The spores (conidia) which arises from the surface of the lesions in most species, soon drop off and are borne by the wind to other barley plants. The fungus oversummers in the old diseased straw or in the conidial stage, awaiting favorable temperature and moisture conditions, which usually appear when the volunteer or sown grain first sprouts. Probably most of the species may be carried by the barley seed.

Hot-water treatment (p. 79), organic mercuric solutions (p. 80) or dusts (p. 82), or strong formaldehyde solution (p. 79) will eliminate the fungus when borne internally in the seed, while the ordinary dusts or liquid treatment will control that caused by spores borne externally. These measures, however, are usually unprofitable with those species (net, spot, and rusty blotch of barley) producing several generations of spores during the life of the host. Many grasses are hosts for these fungi, including common wild barleys (*Hordeum murinum, H. nodosum*, etc.), thus providing a constant source of infestation. With the exception of stripe disease of barley (*Helminthosporium graminem*), seed treatment for *Helminthosporium* disease is ineffective. The breeding and selection of resistant varieties offers the best means of control.

SPOT BLOTCH

Spot blotch (*Helminthosporium sativum*) attacks both barley (fig. 23) and wheat but is most prominent on barley. The spots or blotches appear late in the season after the barley has begun to tiller. The lesions or spots are oval and variable in size. They are dark brown in color and not restricted by the leaf veins. An excessive number of lesions results in leaf pruning, which in turn causes shriveling of the seed. Young seedlings are frequently destroyed and surviving plants are materially weakened. The germ end of both wheat and barley is darkened by these attacks and germination seriously affected. Black tip of wheat has been found to be caused by this fungus.

Seed treatment by the hot-water method (p. 79), formaldehyde dip (p. 79), or organic mercuric dips (p. 80) and dusts (p. 82) will give partial, but not complete, control of the disease due to seed-borne spores (p. 5). Resistant varieties afford the only satisfactory control because of reinfection from surrounding diseased plants during the growing season. The spot-blotch spores may remain viable for

three years, and living mycelium is carried over in old straw. Many physiologic forms are known. Some resistant varieties of barley have been found, including Velvet, Comfort, Glabron, and Vaughn. All varieties of wheat tested have proved susceptible.

Fig. 23.—Spot, or late, blotch of barley (*Helminthosporium sativum*) on the dorsal and ventral sides of barley leaves; *A*, large form of blotch; *B*, small form of blotch.

NET BLOTCH

Net blotch (*Helminthosporium teres*) attacks barley (fig. 24) and grasses belonging to the same genus. It is commonly found on wild barley grass (*Hordeum murinum*), and as this grass is common in all barley areas, a constant source of infection exists. Net blotch forms small, lacy, light-olive-brown lesions, but slightly restricted by leaf veins. It appears earlier than other *Helminthosporiums* (p. 35) owing to its ability to grow in higher temperatures. The first fall rains bring out this fungus on volunteer barley, which soon appears as though badly droughted. From this source the sown barley fields are infected. As the generations occur frequently, seed treatment does not control it. Securing resistant varieties offers the only certain remedy. Vaughn is the only known variety highly resistant to net blotch.

Fig. 24.—Net blotch of barley (*Helminthosporium teres*).

STRIPE DISEASE OF BARLEY

Stripe disease of barley (*Helminthosporium gramineum*) is confined to cultivated and wild barleys. At least two physiologic forms are known. It occurs in all parts of California and regularly causes considerable losses. The leaves bear the lesions, which appear as long stripes (fig. 25). These stripes destroy the connecting tissue and the wind flays the leaf into separate strips. The spores (conidia) are brown and appear in the smutty stripes. The plants attacked seldom produce seed.

The fungus sporulates at the time the barley blossoms, falls upon the floral parts, germinates, and grows into the seed, where the fungus becomes dormant until the seed is sown and begins to grow. The fungus threads then grow with the plant until flowering time, when the plant is destroyed.

The spores infect best at temperatures from 50° to 54° F; above this, infection decreases until at 68° F no further infection occurs. Stripe disease is effectively controlled by the hot-water method (p. 79) and practically controlled by organic mercuric solutions (p. 80).

Because of the difficulty of securing artificial infection, little progress has been made in securing resistant varieties.

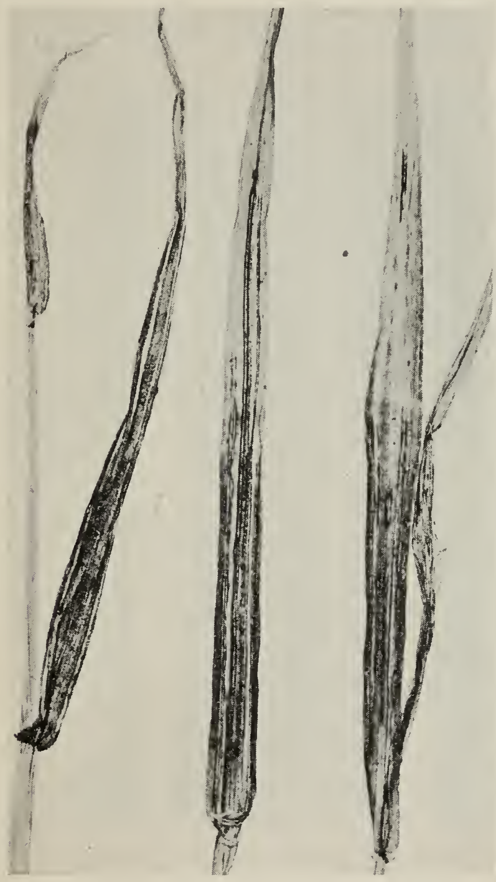

Fig. 25.—Stripe disease of barley (*Helminthosporium gramineum*).

FALSE STRIPE OF BARLEY[3]

Barley plants, about the heading period, sometimes present stripe conditions in the leaves (fig. 26). When the disease is caused by stripe disease (*Helminthosporium gramineum*) (fig. 25) the stripes finally

[3] The cause of false stripe of barley is not known. It is discussed at this point because it is so often confused with stripe disease, described just previously.

turn dark or black because of the numerous spores (conidia). At maturity the leaves split longitudinally. False stripe differs from stripe disease in the absence of the darkened stripes and an entire absence of spores. All of the leaves are attacked in the true stripe disease, but some leaves always escape with the false stripe. The plants attacked by false stripe produce seed, although it is impaired in quality and quantity, but the stripe-diseased plants do not produce seed.

Fig. 26.—False stripe of barley (cause unknown). The leaf on the left is normal. The dark spots are spot blotch.

SPOT BLOTCH OF OATS

Spot blotch of oats (*Helminthosporium avenae*) is very similar to spot blotch of barley. It occurs in California but is of little importance economically. (See p. 35 for general description of this class of diseases.)

RUSTY BLOTCH OF BARLEY

Rusty blotch of barley (*Helminthosporium californicum*) attacks the crop late in the spring after the temperature has risen beyond the point favorable for other leaf blotches (*Helminthosporium* spp.). The lesions are rusty brown in color, irregular, and frequently large (fig. 27). Late-sown grain is most seriously affected, resulting in leaf pruning and poorly filled kernels. It is carried on wild barley (*Hordeum murinum*).

Fig. 27.—Rusty blotch (*Helminthosporium californicum*) on Abyssinian barley (*Hordeum deficiens*).

Seed treatment is ineffective, but breeding for resistance offers effective control. Chevalier barley is immune and hybrids with it may also carry immunity.

BROWN SPOT OF RICE

Four or more species of *Helminthosporium* (*Helminthosporium oryzae, H. macrocarpum, H. sigmoideum,* and *H. maculans*) are known to attack rice, but the difference between species is only micro-

scopic, so that they may be discussed together. The severest damage occurs in Italy, in Asiatic countries, and in the southern states.

Helminthosporium diseases attack rice from the seedling to maturity, causing great damage in certain areas. Grass hosts, like barnyard grass (*Echinochloa crus-galli*), carry these diseases. The fungus is borne internally and externally by seed and by old infected straw or is carried over in infected soil. The attacks are noticed first on the leaves as small brown lesions, which are more marked on the lower side of the leaf. The enlarged lesions darken in the middle but the borders are yellowish. Early leaf pruning follows and at maturity blasted heads result. The optimum temperature is 72° F and its range varies from 60° to 104° F.

Seed treatment by the hot-water method (p. 79) gives complete control where reinfection from other sources does not occur.

Securing resistant varieties seems to be the the only certain protection. Physiologic forms exist. Certain varieties of rice possess considerable resistance but none are known to be immune.

LEAF SPOT OF MAIZE

Leaf spot of maize (*Helminthosporium turcicum*) attacks not only maize but also Sudan grass and perhaps related crops. The spots appear on the leaves in elongated buff-colored lesions. Under exceptional conditions severe damage to corn may occur. It is common in certain parts of Asia and occurs in the southern states. There is no known remedy and resistant varieties have not been found. Importations of corn from areas carrying the disease should be sterilized (fig. 31).

RHYNCHOSPORIUM DISEASES

BARLEY SCALD

Barley scald (*Rhynchosporium secale*) attacks cultivated barley (fig. 28) and wild barley (*Hordeum murinum*), rye, Orchard grass (*Dactylis glomerata*), wheat grass (*Agropyron repens*), and brome grass (*Bromus inermis* and other species). Barley scald is doubtless the most destructive disease to barley in California, especially in the northern half of the state.

The fungus begins its attack early in the fall soon after the barley is sown, or as soon as cool weather appears, and reaches its maximum severity of infection in December-sown barley; it does not infect severely barley sown after February.

The leaves (blades and sheaths) and heads are severely attacked, forming lesions oval (lenticular) in shape with brown margins and blanched or white centers. The blanched spots suggested the name 'scald' for the disease. Leaf pruning, premature ripening, shriveled kernels, blanked florets, and lodging result from attacks of scald.

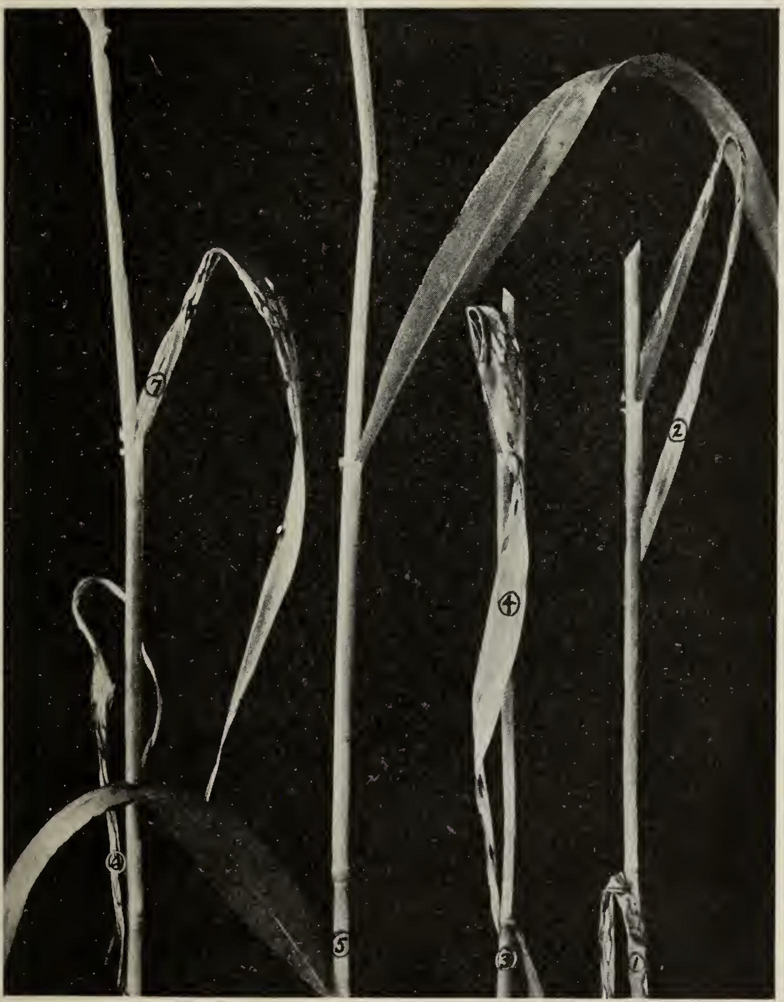

Fig. 28.—Effect of leaf pruning through scald attack; Nos. 1, 2, 3, 4, 6, and 7 show scald; No. 5 is a scald-free plant.

The fungus may be carried in the seed, but seed treatment has little effect on the control of the disease because of repeated infection from volunteer plants, wild barley, and infected sown barley. Appar-

ently several generations occur during the growing season of the crop. Resistant varieties offer the only relief, and the breeding of resistant barleys is complicated by the existence of physiologic forms. The known resistant varieties include Sacramento, Vaughn, Abyssinian, and a number of unnamed barley hybrids. These latter offer a solution of the scald problem.

MILDEWS

POWDERY MILDEW

Powdery mildew (*Erysiphe graminis*) attacks wheat, barley, rye, and oats, as well as many grasses. There are many specialized physiologic forms. Mildew is mildly parasitic in most forms, causing early leaf pruning with consequent weakening of the plant, followed frequently by lodging. The mature mildew spot or lesion is rusty brown in color and fainter on the lower side of the leaf; this distinguishes it from *Helminthosporium* spots, which appear equally colored on both sides of the leaf. One form is especially severe on barley, causing yellowing even where the leaves do not show by the gray spores (conidia). The diseased plants become weakened and stunted and yield shriveled grain.

Dry winds check the mildew, but the surest remedy is found in resistant varieties. Varieties of wheat found immune include Norka and Michigan Amber 29–1–1–1. Among barley varieties, Goldfoil and Sacramento are practically immune. No immune or highly resistant varieties of cultivated oats are known. Flowers of sulfur dusted upon the plants prevents and destroys mildew.

Specialized forms have been found severely attacking all species of wheat. The distinctly resistant wheats include Khapli, Russian emmer, Spring emmer, Persian, and *Triticum vulgare* var. *caesium* among the common wheats. Wheat mildew cannot attack oats, barley, and rye.

All the cultivated and wild oats are susceptible to oat mildew, but oat mildew cannot infect other cereals.

Mildew attacks all the cultivated barleys but is unable to infect the wild barleys, except *Hordeum spontaneum*, which is very susceptible. Immune and slightly resistant varieties offer a foundation for breeding resistance to mildew into desirable but susceptible local varieties.

MILDEW OF SUNFLOWER

Sunflowers are attacked by a leaf mildew (*Erysiphe cichoracearum*) that is common on a large number of cultivated and wild plants,

including tobacco, cucumbers, squashes, pumpkins, hops, chicory, and mint among the cultivated plants, and star thistles and other composites and cucurbits among wild plants. The attacked surfaces are covered with a white or pink mold which later bears brown fruiting bodies (perethecia) in clumps or scattered. Dusting of flowers with sulfur offers relief.

Downy mildew (*Plasmorpara halstedii*) also occurs on sunflowers but appears to be of no economic importance.

Fig. 29.—Downy mildew of wheat (*Sclerospora macrospora*). The distorted heads produce no grain.

DOWNY MILDEW OF WHEAT AND BARLEY

Downy mildew of wheat (*Sclerospora macrospora*) is found in Europe and in central United States. It occurs in California occasionally on heavy, damp, cold soils. Downy mildew is not a very serious disease in this state.

The wheat plants when attacked show excessive tillering and distortion in stem, leaf, and head (fig. 29) and do not mature seed.

Numerous small minute bodies (oospores) imbedded in the leaf tissue may be seen when the leaf is held up to the light. Recently (1929) downy mildew has been found on barley in California.

In Italy it attacks wheat and maize especially but may be found on oats, barley, rice, and many wild grasses, including *Phalaris, Phragmites, Glyceria,* and *Agropyron.* No practical methods of control can be suggested except crop rotation and resistant varieties.

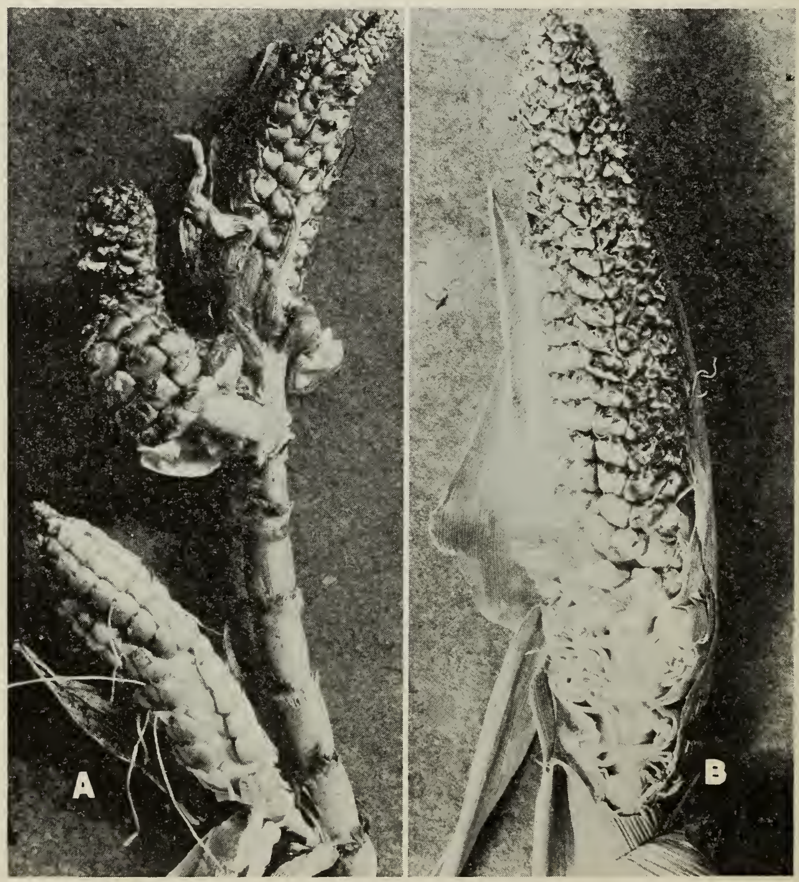

Fig. 30.—*A*, poor ear resulting from downy mildew; *B*, ear blasted by downy mildew. (After Weston, U. S. Dept. Agr.)

DOWNY MILDEW OF MAIZE

Several species of downy mildew, including *Sclerospora graminicola,* are severely injurious to maize (fig. 30) in India, Philippines, Java, Formosa, and other Pacific Islands. It has not been found in California. Besides maize, it attacks teosinte, and sorghums.

The disease appears after the plants have produced three or four leaves and continues until tassels are developed. Infected plants show a yellowing of the leaves in restricted striped areas in which a whitish spore down (conidiospores) appears. Abnormal leaves and abortive ears follow, resulting in partial or complete sterility. The spores (conidia) are produced at night when dews assist in germination. The fungus is found in all parts of the plant except the root.

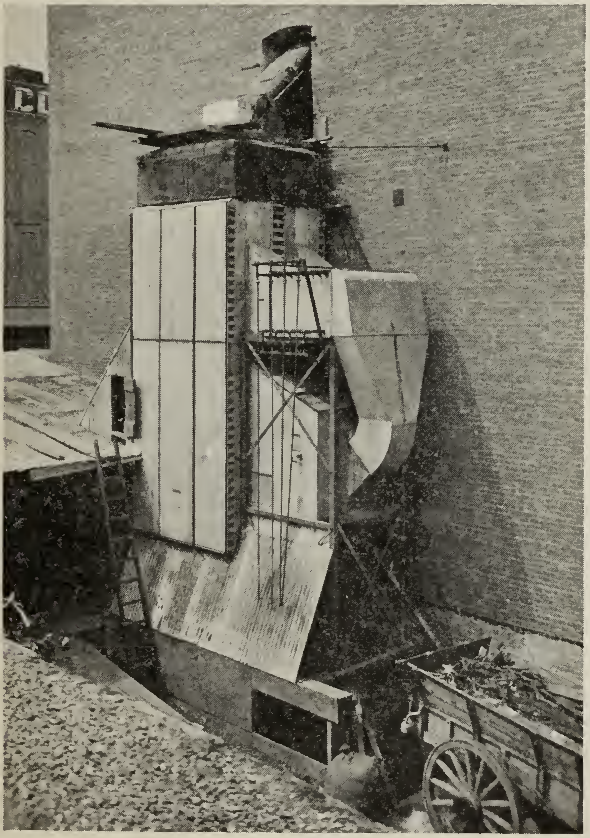

Fig. 31.—Equipment for sterilizing maize at San Francisco to prevent the entrance into California of downy mildew and other Asiatic cereal diseases.

Maize seed suspected of carrying downy mildew should be treated with concentrated sulfuric acid to destroy the spores. The same treatment is successful with sorghum, teosinte, and coix seed. Heat sterilization of maize imported from Asia is enforced at the ports of entry. The equipment for this sterilization is shown in figure 31.

DOWNY MILDEW OF MILLET

Downy mildew (*Sclerospora graminicola*) has been found on millets in Iowa and Florida. This mildew has been transferred to pop and dent corn, teosinte, and proso, or hog millet (*Panicum miliaceum*), but has not been known in the United States to infect maize in the field under natural conditions. In the field, downy mildew attacks foxtail millet (*Chaetochloa* [*Setaria*] *viridis*) and Hungarian, or German millet (*Setaria italica*). The infected plants are stunted. Some die in the seedling stage, and many appear as dwarfs; none outgrow the disease.

The spores (conidia) attack through the air and also (oospores) overwinter in the soil, attacking the young seedlings in the following spring.

ANTHRACNOSE DISEASES

ANTHRACNOSE

Anthracnose (*Colletotrichum graminicolum*) attacks wheat, barley, oats, rye, millet, and Sudan grass, on which it is especially severe. It occurs also on many other grasses. Another species (*C. fulcatum*) attacks grain and saccharine sorghums.

The attacked plants show a decrease in vigor and the grain is shriveled. On the bases of culms and glumes the small black fruiting bodies of the disease appear. Anthracnose is sometimes confused with rust. The disease is carried in the seed or by infected straw in the soil. If the seed were the only source of infestation, seed treatment with formaldehyde (p. 79) hot water (p. 79), or certain of the organic mercuric solutions (p. 80) or dusts (p. 82), would serve, but soil infestation and grass hosts carry the infection. Screening and blowing out the shriveled seed by seed-cleaning machinery reduces the seed-borne attacks. Fulz wheat is reported as resistant.

ANTHRACNOSE CANKER OF FLAX

Anthracnose canker (*Colletotrichum lini*) attacks flax seedlings, appearing first as cankers, or lesions, on the seed leaves. The disease germs are borne internally in the seed. The plants which are not killed in the early stages show purple spots and produce shriveled seed. The plants usually wilt or 'damp off' and under damp conditions are often covered with a salmon-pink mold and the dark hairlike bodies characteristic of the disease.

As the parasite is borne inside the seed, ordinary seed treatment fails to control it. Separating out the shriveled cankered seed will reduce the attack. The hot-water treatment will control it, but solutions of organic mercuric compounds are suggested.

FUSARIUM DISEASES

PINK ROOT OF CEREALS

Pink root, caused by *Fusarium culmorum* var. *leteius,* is common throughout the state and the whole Pacific Coast on wheat, barley, oats, rye, and several grasses. *Fusarium avenaceum* and *F. roseum* are perhaps identical with this fungus. It is found in the eastern states to a lesser degree, being exceeded by scab (*Gibberella saubinettii*).

The destructive attack from pink root may be found from the early seedling stage to the dough stage of these cereals. Usually a pink color is detected in the fungus growth, visible to the naked eye, on the diseased plants. Many diseased plants die prematurely and all are reduced in yield and the quality of the seed impaired.

It is borne on or in the seed, but infested soils also harbor it from one end of the year to the next. While its ravages occur each year, it seldom reaches large proportions.

Seed treatment with copper-carbonate dust (p. 81) reduces the infection, but organic mercuric dusts (p. 82) and formaldehyde dips (p. 79) are even more effective. Resistant varieties alone will give complete control. At present no highly resistant varieties are known.

SCAB OR SEEDLING BLIGHT OF WHEAT

Seedling blight of wheat is the name given this disease (*Gibberella saubinettii*), but it attacks barley, rye, oats, and maize. It has not been found in California, where it appears difficult for the disease to establish itself, owing probably to climatic conditions unfavorable to it. Scab is replaced by pink root (*Fusarium culmorium* var. *leteius*), a similar disease. The diseased seedlings show a light brown rot below the ground, especially to the tillering stage, after which it spreads to the head and is then called scab. A salmon-pink dust-like mycelium is frequently evident on the chaff. The severity and spread of scab depends largely upon humid air conditions at heading time—an unusual condition for California.

The summer spore stage (conidial) is known as *Fusarium gramineum*. This stage is detected by the pink or red color caused by mil-

lions of these spores. The winter spore stage is detected by the large round bodies (perethecia) which bear spores called ascospores. This stage is the common form of the disease in corn stalks and from them it is spread by the wind. Plowing under these old stalks helps to check its spread.

Barley seed infested with scab organisms causes sickness when fed to swine. Barley imported for feeding from infested areas should be carefully inspected for scab.

Infested fields of wheat or barley when plowed under, infect the soil for the following crops of cereals or maize. Maize carries over the disease to wheat and other cereals. The seed wheat and barley usually carry the disease internally and externally.

Seed treatment with organic mercuric compounds (p. 80) is recommended since it prevents smuts and stripe disease also. Seed treatment reduces the damage but does not prevent attack from infected soil. The remedy is the selection of disease-resistant varieties and rotations not involving susceptible crops. The following wheats have been found resistant: Red May (several selections), Poole C. I. 5653, Kanred, Glyndon Fife, Minnesota 163, Hayne Bluestem, Norka, Progress, Resaca, Illinois, and Prelude. Barleys resistant to scab blight include Meloy C. I. 1176, Club Mariout C. I. 261, Manchuria, Minnesota 452, Svansota, Minnesota 440, Peatland, and Minnesota 452.

PINK ROT

Pink rot of maize (*Fusarium moniliforme*) is the commonest of all corn diseases. It is visible in more than 75 per cent of all ears of corn in California fields and is spread, in the majority of instances, by the attacks of the corn ear worm (*Chloridea obsoleta*). The moist condition about the worm is a perfect medium for the spores, which are always present in the air. To a much smaller extent boil smut and birds spread this disease. (See also p. 29.)

In selecting seed corn, the ears which are visibly discolored by the pink rot should be rejected. The others should be cut across the butt and tip ends. If discoloration appears in the cob, the ear should be rejected. After rejecting all ears found to be visibly infected, some are sure to carry the disease. This seed corn should be treated with one of the mercuric dust compounds (p. 82), which will reduce the seed infestation. The breeding of special lines of maize with ears sufficiently well protected by long thick husks offers the best remedy (fig. 34).

Pink rot (*F. moniliforme*) infects wheat, oats, and barley, and may be the cause of disease in grain following maize.

FLAX WILT

Flax wilt (*Fusarium lini*) causes the destruction of flax at all stages of growth and is frequently a limiting factor in flax production. The attack is made from the soil giving rise to the term 'soil sickness.'

The disease is carried into new soil by infected seed. It spreads and seed sown on new land should be treated with formaldehyde (p. 79) or one of the organic mercuric dips (p. 80). The only certain relief lies in planting resistant varieties. The following have been found highly resistant: Redwing, Chippewa, and Winona. At least nine physiologic forms are known. This fact complicates the breeding for resistant varieties, already rendered difficult in flax by natural outcrossing.

Fig. 32.—Foot-rot (*Ophiobolus graminis*) on wheat. (From New South Wales Bul. 102.)

FOOT-ROT OF CEREALS

Foot-rot (*Ophiobolus graminis*) also called take-all, white head, etc., is known to occur abundantly in Europe, Australia, Canada, and the United States including California. It attacks wheat (fig. 32) severely and also injures barley, rye, and many grasses, but rarely oats.

The fungus is carried in diseased straw and grass hosts. The attack occurs in the soil through the roots. Injury is greatest near 54° F. Early planting, cool weather, and abundant moisture favor the disease.

Seedlings may be killed, but usually the appearance of the disease is noticed after the plants have headed. Plants attacked mature too early, showing a characteristic blanching of the head. Either no grain or very shriveled grain is produced. Just above the crown under the leaf sheathes on the stalk, a black shiny surface (the mycelial plate) will be seen. Unless favorable temperature and moisture conditions exist, the final stage (perithecial) does not appear in California. This final stage is characterized by small black bodies (perithecia) filled with spores (ascospores). The disease is carried by the wind and animals.

Complete crop rotation for at least two years is required to rid the soil of the fungus. Burning of all stubble, followed by clean culture, reduces the disease. Shallow, late tillage checks the rapid spread, but deep plowing favors the survival of foot-rot. Oats are not subject to the disease, thus affording a good cereal rotation.

No immune varieties of wheat are known, but considerable difference in varietal resistance exists. Forward and Dawson show definite resistance. Seed treatment is valueless except in preventing spores from being carried into clean soil.

SEPTORIA DISEASES

Septoria attacks wheat, rye, barley, maize, and many grasses. Speckled blotch of oats is caused by *Septoria avenae,* speckled blotch of rye by *Septoria passerinii, Septoria* spot of sunflower by *Septoria helianthi,* Glume blotch of wheat by *Septoria nodorum,* and speckled leaf blotch of wheat by *Septoria tritici.* In California only speckled leaf blotch of wheat is of economic importance.

SPECKLED LEAF BLOTCH OF WHEAT

Speckled leaf blotch of wheat (*Septoria tritici*) annually causes severe losses. Seedlings are often killed and the surviving plants greatly weakened, causing lodging, premature ripening, shriveled grain, and reduced yields.

At the time of heading or earlier, light spots about the size of pinheads may be noticed in the leaves. In resistant wheats these do not fruit, but in susceptible varieties black fruiting bodies (pycnidia) appear thickly scattered over the leaves, as shown in figure 33. The

pycnidia send forth colorless spores (pycnospores) visibly in motion. From 11 to 15 days are required for a generation of new spores (conidia) to appear repeating the cycle. In this manner several generations occur during a single growing season.

The fungus prefers the cool moist winter season and for this reason is particularly severe on grain sown very early, especially in the moist areas in the northern portion of the state. The most favorable temperatures lie about 75° F, and the extreme limits are found between 37° and 90° F. The disease is carried over mainly in old straw by the spores (pycnospores) borne in the black fruiting bodies. These spores are spread by the wind to adjacent fields.

Fig. 33.—Speckled leaf blotch of wheat (*Septoria tritici*); *A*, black fruiting bodies (pycnidia) two and a half times normal size; *B*, black fruiting bodies and destroyed leaf tissue.

Great variability in varietal resistance to speckled leaf blotch has been found in wheats. Most varieties are susceptible. Escondido is resistant. Several wheat hybrids have not been attacked over a period of years, indicating that high resistance can be bred into desirable varieties.

SEED MOLDS

Seed treatments by the hot-water method (p. 79) and by organic mercuric solutions (p. 80) clean the seed of the mold spores, but do not prevent reinfection from the soil and air.

Early harvesting of disease-free corn seed, which should be thoroughly dried at once, may prevent much of the seed infestation. Climatic conditions in California differ radically from those in the eastern corn states, where freezing weather prevents the increase and spread of these diseases in the seed corn. Under California conditions, humid weather, with temperatures favorable to the growth of these fungus diseases, begins at harvests and lasts until after planting time. Seed corn kept thoroughly dry over this period may be much freer from disease.

BLUE MOLD

Blue mold (*Penicillium glaucum*) is found generally in the soil and air and causes seed-germ damage and seedling blight. It is detected by the powdery blue dust of the spores and has been mistaken for blustone in seed grain which has failed to germinate in the soil. It is found on all seed wheat, barley, oats, rye, rice, sorghum, and maize not treated with chemical fungicides.

BLACK MOLDS

Black molds (*Penicillium oxalicium* and *Aspergillus niger*) attack maize and sorghum seed-germs and seedlings. They follow the attack of the ear worm, boil smut, and other injury to the maize ear. The spread of the fungus in storage seriously impairs the quality of corn and injures its germination. *Aspergillus niger* also attacks seedlings of wheat, barley, oats, rice, and rye.

YELLOW MOLD

Yellow mold (*Aspergillus flavus*) is not so common as black or blue molds but is more destructive to seed-germs of all cereals and maize. Maize with pendent ears usually escapes attack.

SEED-BORNE DISEASES OF MAIZE

Seed-borne diseases of maize include a number of diseases discussed in connection with other hosts or under other headings—pink rot (p. 50), *Gibberella* rot, called scab or seedling blight when it attacks wheat (p. 49), dry rot (p. 63), blue mold, black mold, and yellow mold (p. 54). Fuller discussion of these will be found on the

pages indicated. Also included are a number of diseases not discussed elsewhere in this bulletin—black-bundle, *Diplodia* rot, scutellum rot, and *Pythium* root rot.

The characteristic colors indicated in the common name serve to identify some of these diseases, but *Diploidia* rot and black-bundle are not so readily recognized by color. *Diplodia* rot can be detected by the black fruiting bodies (pycnidia) which appear on the old stalks or on the husks. Black-bundle rot is identified by the blackened vascular bundles found running lengthwise of the stalk. By breaking the stalk crosswise the diseased bundles may be found in any part of it, and in the ear. The last two diseases have not been found in California. The other rots are common and widespread but the commonest and most destructive is the pink rot (*Fusarium moniliforme*). Descriptions of dry rot, *Gibberella* rot, and scutellum rot will be found on pages 63, 49, and 58, respectively.

The effect of these rots is seen in barren stalks, nubbins, early breaking down of stalks, premature ripening, or broken or bent stems of the ears. All these rots are carried in diseased plants and propagated or held in a viable state in the soil, ready to infect young seedlings. When once the fungus has made its entrance into the plant it may continue its growth until the plant matures its crop, thus infecting the seed. If such diseased seed is sown, diseased plants are the result, with reduction in the quantity and quality of the crop.

Diseased seed is detected by removing a few kernels from the ear and germinating the seed in the rag-doll or other germinators.[4] Ears which show plainly diseased seed should be rejected, and only disease-free ears used for seed. A more rapid, but perhaps less efficient method, lies in clipping off the butt and tip ends of the ears reserved

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[4] The modified rag-doll germinator is made by placing upon a strip of glazed butcher's paper, 9 inches wide by 6 feet long, a similar-sized strip of good-quality bleached muslin. The paper serves to prevent the spread of the molds. The cloth is boiled in water before being placed upon the paper. The kernels from each ear are laid across the germinator in a row which is numbered to correspond with the ear number. The kernels are all placed germ side down. When all the kernels are placed, the germinator is rolled into the rag doll and tied at the ends. It is then placed on end in a quart of water and covered with a wet gunny sack to prevent drying out. The temperature of the doll should be kept between 80° and 85° F. The test should be completed between 5 and 9 days.

The glass-top sand-box germinator is constructed by making a long wooden box, 8 to 12 feet long by 2 to 3 feet wide, and 4 inches deep, and supporting it with four legs. The bottom is covered with a clean wet cloth and filled to within 1 inch of the top with clean wet sand. A strip of muslin is then placed over the sand and the corn laid in rows, 8 kernels to each ear. A 1-inch square is allowed to each kernel. Panes of glass are then placed over the seed. The sand-box germinator is superior to the rag doll in preventing the mold from spreading from kernel to kernel.

for seed. If colors characteristic of the molds described above appear in the cross section of the cob, the ear should be rejected. Care must be taken not to confuse natural colors with diseased tissues.

Seed treated with effective organic mercuric compounds (p. 80) is freed from the seed-borne fungus diseases and may bring a slightly increased yield. Chemical treatment of seed is not a complete preventive, for these diseases attack even though the mercuric compounds penetrate fully into all parts of the corn kernel. The beneficial effects appear greatest for early plantings when the soil is cold and wet or where the soil fertility is poor. Plantings made at a later date or in fertile soil do not reflect the same benefits from seed treatments.

Fig. 34.—*A*, well-covered, partly erect ears; *B*, poorly covered ears; *C*, well-covered pendent ears, which offer better protection from birds and pink rot.

Attacks of these root-rot diseases from various sources occur during the subsequent life of the plant. The corn ear worm is the most prolific source of disease infection, for the spores of all these rots are carried by the wind and readily grow in the juices resulting from the attacks of the worm on the ear. In this manner the fungi enter the seed, find lodgment, and continue the infestations. No complete relief can be expected except through resistant varieties. Resistance in this case, however, may be increased through long, thick husks which protect the ear from worm attack. Boil smut is likewise well controlled by the same husk protection over the ear. Bird attacks also expose the ear to fungus infestation. Pendent ears, with strong protective husks (fig. 34), somewhat discourage birds. The selection of these protected ears for seed will reduce the losses carried through ear infestation.

Breeding for varieties with good husk protection offers a positive method for reducing these injuries to the corn crop. Strains of maize resistant to pink rot have already been found in King Philip hybrid, the common grain-producing variety for California.

BLACK-BUNDLE DISEASE OF MAIZE

Black-bundle disease (*Cephalosporium acremonium*) is identified by the blackening of the vascular bundles in the pith of the stalk (fig. 35). It is detected by excessive suckering, and ear development at many joints, many of them multiple in form. Reddening and purpling of the leaves, barren stalks, and nubbins result.

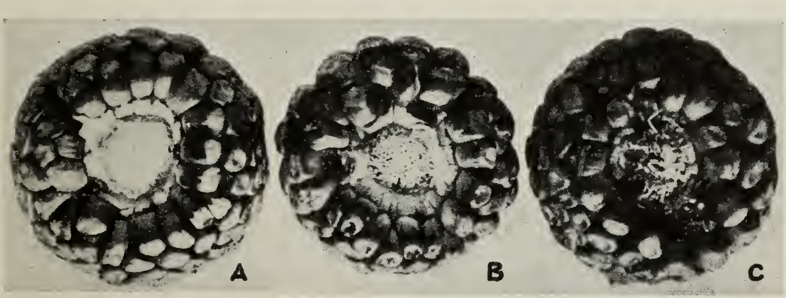

Fig. 35.—*A*, bright, healthy shank attachment; *B*, dark vascular bundles associated with black-bundle disease (*Cephalosporium acremonium*); *C*, shredded condition indicating that the ear came from a rotted and prematurely dead shank. (From Illinois Agr. Exp. Sta. Bul. 225.)

Infected ears carry the organism in the seed. No ears from infected plants should be used for seed. Seed treatment with organic mercuric compounds (pp. 80, 82) assists in reducing the disease. The selection of disease-free seed by the rag-doll or sand-box germinator method is advised, but the rejection of ears with cobs discolored at the base is even more effective and rapid. Breeding for resistant varieties should give the best results. The black-bundle disease has not been found in California maize.

DIPLODIA ROOT ROT, EAR ROT, AND SEEDLING BLIGHT

Diplodia rot (*Diplodia zeae*) has not yet been found in California, as it prefers summers with high humidity. *Diplodia* is carried by the infected seed and gives rise to weakened or dead seedlings. The surviving plants make an irregular and reduced growth. There is little evidence that the disease advances up the stalk to the ear.

The fruiting bodies (pycnidia) appear as very small, dark-colored specks under the surface, which break forth, spreading their spores in the air to be carried to other growing plants. Corn stalks three years old have been found to carry live spores in the very small dark-colored specks (pycnidia) under the rind (fig. 36).

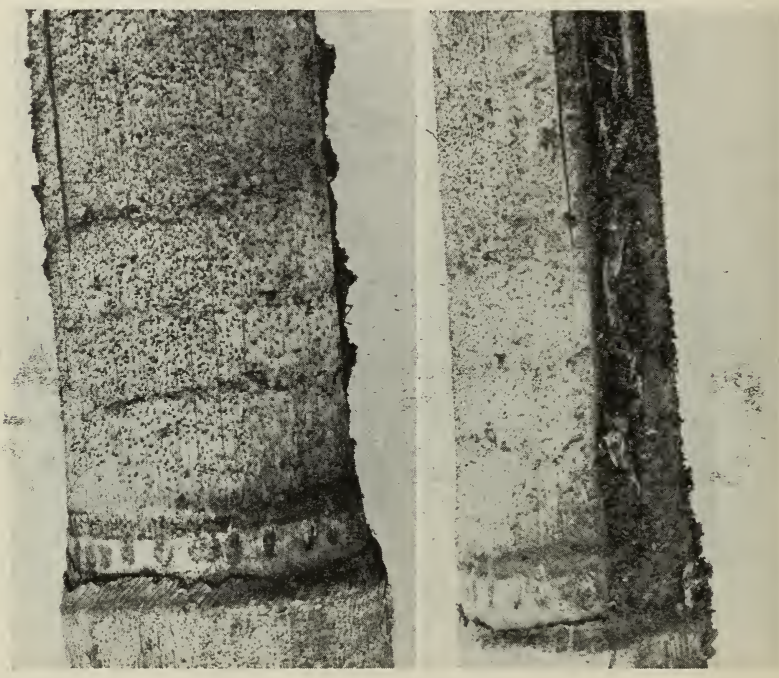

Fig. 36.—Old corn stalks from the previous year's crop showing black fruiting bodies (pycnidia) of *Diplodia* rot (*Diplodia zeae*). (From Illinois Agr. Exp. Sta. Bul. 225.)

Detection of infected ears by the rag-doll germinator and treating the seed with organic mercuric compounds (p. 80) are recommended. Selecting resistant strains offers the best remedy. Early harvesting, followed by thorough drying and preserving of the seed, greatly reduces *Diplodia losses.*

SCUTELLUM ROT

Scutellum rot is caused by a common mold (*Rhizopus* spp.) affecting the inner portions of the seeds of maize and other cereals. The diseased seed is either destroyed or weakened, causing poor seedling growth. The most outstanding effect of *Rhizopus* is seen in the reduction of the early vigor of the seedling, resulting in late maturity, which is generally reflected in a corresponding reduction of the crop.

Rhizopus-affected seedlings present a conspicuous gray mycelial growth (fig. 37), as compared with the pink-colored growth caused by *Fusarium*. Seed from disease-free ears remain free of the disease in the soil and give rise to *Rhizopus*-free plants. Effective organic mercuric dusts may reduce the seed-borne organisms.

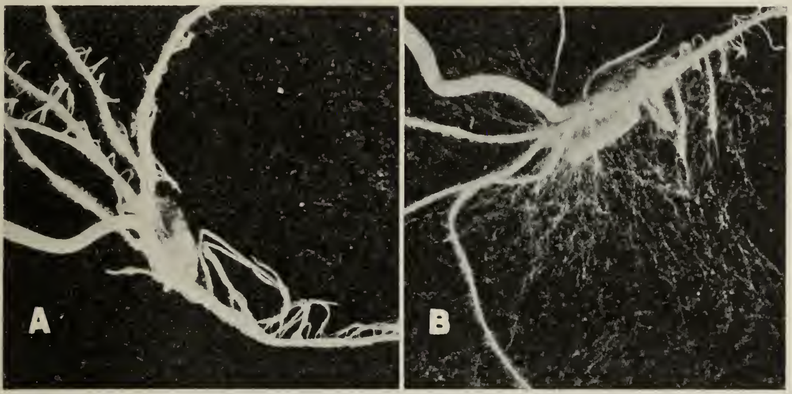

Fig. 37.—Maize kernels: *A*, resistant to *Rhizopus*; *B*, susceptible maize infected with *Rhizopus*. (After Illinois Agr. Exp. Sta. Bul. 225.)

PYTHIUM ROOT ROT

Pythium root rot (*Pythium* sp.) attacks dent corn in the corn belt, entering the roots from infested soil and causing wilting and destruction of seedlings. The plants surviving are reduced in size and vigor. Soil temperatures from 54° to 61° F with high soil moisture favor the disease. These conditions are common in fields planted very early. No remedy is offered, except crop rotation, since the disease is carried in the soil. It has not yet been found in California.

SEEDLING BLIGHTS OF RICE

Seedling blight and 'stack-burn' are associated troubles of seed rice and are due to fungus diseases. 'Yellow grains' in Asiatic rice are caused by a fungus (*Protoascus colorans*). Rice grains flecked with spots colored brown or yellowish brown or grains wholly yellow-brown are included in the term 'stack-burn.' In the Mississippi Valley rice fields where the summer climate is humid, the number of fungi causing stack-burn is greater than in California. The following fungi borne by the seed and causing discolored seed, seed injury, and seeding blights of rice have been identified: *Mycelia sterilia,* a leaf-spotting disease forming small black bodies (sclerotia) in the kernel;

Piricularia oryzae, rotten-neck (p. 60); *Helminthosporium freda de haan*, leaf spot; *Penicillium glaucum*, blue mold (p. 54); *Aspergillus flavus*, yellow mold (p. 54); *Fusarium* spp., pink mold, *Sclerotium oryzae*, seedling blight (p. 42); and *Sclerotium rolfsii*, late blight (p. 60). In California *Alternaria* sp. has been found causing leaf-flecking, blast, and seedling infection. The dry air during the California rice-growing season is responsible for the light attacks of these fungi and the better germination of California-grown seed.

The hot-water treatment (p. 79) gives complete control of these diseases even when borne internally in the seed. Effective organic mercuric dips (p. 80) are safer and more readily applied. The resistance of a number of varieties indicates that relief can be secured through varietal resistance.

ROTTEN-NECK OF RICE

Rotten-neck or blast (*Piricularia oryzae*) attacks rice in all Asiatic countries, Italy, and the United States. When young plants are attacked brown spots with ash-gray centers appear on the leaves. Where numerous, the spots or lesions coalesce and destroy the leaf prematurely. From the lesions arise branches bearing oval 3-celled spores. Young seedlings may be destroyed but the heaviest damage occurs when the plants are blooming. The neck or stem of the rice head weakens and breaks. The head either fails to mature or produces mainly blasted florets or grains. The spores set free at this stage may germinate at once to spread the disease.

Crop rotation is the best known remedy, coupled with the destruction of grass hosts, especially crab grass (*Panicum sanguinale*). Japanese and Italian rices appear to be the most resistant but no immune varieties are known.

SCLEROTIAL DISEASES

SCLEROTIAL DISEASES OF RICE

Sclerotial diseases of rice (*Sclerotium oryzae* and *S. rolfsii*) are the cause of much damage to rice in Asiatic countries and in the southern states, but have not as yet been found in California.

Sclerotial diseases of rice are readily placed by the small brown or black fruiting bodies (sclerotia which appear on the dead or dying plants. These bodies approximate the size of mustard seed.

The sclerotial-disease damage (figs. 38 and 39) to seedlings in the Mississippi Valley is caused mainly by seedling blight (*Sclerotium*

rolfsii). The stand has been at times reduced 50 per cent by this and a later sclerotial disease (*S. oryzae*). The former causes much damage and even death to germinating seeds and seedlings and the latter damages the more mature plants until they fail to fill normally. The fruiting bodies of seedling or sclerotial blight (*S. rolfsii*) are small, brown, and spherical, and those of late blight (*S. oryzae*) are small, black, and glistening. Seedling blight appears early at the seedling stage, while late blight is usually found abundant on plants in midsummer, when it may be detected by the weakness and breaking down of stems.

Fig. 38.—*A*, Kernels of Honduras rice showing black fruiting bodies (sclerotia) on the surface; *B*, healthy kernels of the same variety. (After Tisdale, U. S. Dept. Agr. Dept. Bul. 1116.)

Other hosts include wheat, soy beans, tall oat grass (*Arrhenatherum elatius*), and perhaps other grasses. The spread of these diseases is due to the transporting of the small black fruiting bodies, which float like cork in the irrigation water, and by old diseased straw left on the soil. The fruiting bodies live over for many months in the field.

Japanese types of rice are more resistant than the long-grained varieties, but none are highly resistant. At present no sclerotial diseases of rice have been found in California.

Fig. 39.—*Sclerotium* disease of rice (*Sclerotium oryzae*) enlarged to show destroyed inner portion of rice stem and the numerous black fruiting bodies (sclerotia) of the fungus. (After Tisdale, U. S. Dept. Agr. Dept. Bul. 1116.)

SESAME SCLEROTIUM

A very destructive sclerotial disease (*Sclerotium sp.*) has been found attacking sesame (*Sesamum indicum*). Many of the plants are killed at the fruiting stage and all diseased plants are badly damaged. The black sclerotia are thickly distributed on the culms. The hot-water methods of seed treatment (p. 79) completely eradicates the fungus.

DRY ROT OF MAIZE

Dry rot of maize (*Sclerotium botatacoli*) has been found recently attacking maize both in the interior valley and in the coastal regions. The disease appears late in the development of the plant and is found in the pith of the stalk. It can be recognized by the small black fruiting bodies (sclerotia) found attached to the fiber bundles of the pith. These black bodies are not found on the exterior of the stalk and do not extend upward more than 12 or 15 inches, but may be found below the surface of the soil. The pith carrying the disease may show a pink discoloration similar to that caused by *Fusarium moniliforme*. The pink color however may give place to a gray or tan color. Stalks attacked by the disease are weakened and mature prematurely, causing lodging and reduction in yield. The same disease is carried in common and on blackeye beans. No remedy is suggested, for the disease has been under observation for only a short time.

SUNFLOWER WILT

Sunflowers cultivated in California and Kansas for seed, and in many northern states for ensilage, are attacked by a sclerotial wilt (*Sclerotinia libertiana*). The plants are attacked in the seedling stage but the diseases may continue into the mature plants. Many seedlings are killed. Large black bodies (sclerotia) with white interiors appear on the surface of the crowns, on the roots, and sometimes in the pith.

The disease is spread by means of the sclerotia in the soil and in diseased seed or plant fragments. In the field it may spread by means of threads (mycelium) through the soil from plant to plant. It is also a wound parasite. Beans, beets, cabbage, carrots, cauliflower, Canada thistle, sow thistle, celery, chicory, clover, mustard, hemp, lettuce, onion, potato, radish, and wild sunflowers may carry the disease. Clean culture, crop rotation with immune crops like cereals, grain sorghum, or corn, effectively reduce but do not eliminate the disease with certainty under four years. No highly resistant varieties are known.

SCLEROTIUM DISEASE OF WHEAT

In Idaho a very injurious sclerotium disease (*Sclerotium rhizodes*) has been found attacking wheat, killing large areas in the seedling stage. Dark brown or black fruiting bodies (sclerotia) about the size of a small pinhead, averaging 25 per inch of leaf, identify the disease. Its occurrence is not regular, and but little is known concerning it.

SORE SHIN OF FLAX

Sore shin of flax (*Rhizoctonia sp.*) is very destructive and appears in flax fields in spots varying from a few feet in width to areas more than an acre in extent. The disease first appears on the roots as small brown lesions just beneath the surface of the soil. Later these lesions extend upward and downward. In its later stages the disease reduces the stem to a dry pulp which sometimes breaks in a ragged split. The fungus is soil-borne and enters the plant through the pith, causing wilting and premature death. There is no known remedy except fallow and crop rotation.

PASMO DISEASE OF FLAX

Flax fields infested with pasmo (*Phlyctaena linicola*) show marked brown areas ranging in width from a few feet to a rod or more. The diseased portions of the stems show brown mottles. These mottles, or lesions, become thickly covered with the fruiting bodies (pycnidia). The fruiting bodies hold over in the straw to carry the disease to the next crop. The spores are also carried externally on the seed. The importations of diseased seed from Argentina is undoubtedly the source of the disease in the United States.

To control pasmo, old diseased straw should be burned or plowed under. Infested soil should be fallowed or rotated with crops other than flax. Seed treatment with organic mercuric compounds as dips or dusts is suggested as a partial remedy, especially to prevent its spread on the seed. North Dakota Resistant No. 52, North Dakota Resistant No. 114, and North Dakota No. 155 were found to be more resistant than Argentine flaxes.

MOSAIC DISEASES

MOSAIC DISEASE OF WHEAT

Mosaic disease of wheat (fig. 40) is caused by a filterable virus, an organism too small to be detected by the microscope. Barley and winter rye are also attacked.

The effect of mosaic in wheat is seen in two forms, the rosetting of the seedling and mottling, or mosaic, of the leaves. Such diseased plants either die outright or live to make little or no seed. The mosaic form appears to be the commonest expression of the disease. Infection occurs only in the seedlings and comes mainly from the soil, which may be infected to the depth of ordinary plowing.

In resistant varieties lies the only known remedy. A number of resistant varieties of wheat have been found, including Fultz, Turkey, Kanred, Red Wave, and others. These wheats may serve for breeding purposes.

Fig. 40.—Mosaic of wheat showing dwarfed and rosetted plants. (Photo from U. S. Dept. Agr.)

MOSAIC DISEASE OF CORN

Mosaic disease of corn is characterized by the mottled appearance, most apparent in the young leaves. Mosaic appears in more or less irregular patches or strips of light green surrounded by normal dark-green tissue, or the light tissue may entirely surround small spots of normal green tissue. Sharply defined mosaic gradually disappears as the season advances. In some instances dwarfing of plants and barren stalks have been reported, while under other conditions no reduction in corn yields occur. There may be a number of different mosaics attacking corn and causing corresponding differences in crop damage.

Corn mosaic is carried by the corn aphid (*Aphis maidis*) which may also carry the disease to other host plants, including cane, tobacco, beans, and squash. Resistant varieties afford the only practical method of control.

BACTERIAL DISEASES OF CEREALS

Bacterial diseases are found attacking wheat, barley, rye, oats, maize, sorghums, and millets. Several diseases caused by new species of bacteria have been discovered during recent years. It is probable that further discoveries will be made.

Bacterial diseases are transmitted in the seed, in the soil, and in the air. Portions of diseased plants transported in various ways are also responsible for spreading many of these diseases.

Owing to the ease with which these bacteria are carried in soil, air, and water, seed treatment offers no practical control. Securing varieties resistant to these diseases offers the best means.

Usually only slight injury is caused by bacterial diseases, but there are notable exceptions, such as bacterial wilt of maize, which is very destructive. The damage to crops is difficult to determine accurately, owing to the fact that death seldom follows attack.

BLACK CHAFF OF WHEAT

Black chaff (*Bacterium translucens* var. *undulosum*) occurs on wheat and may cause considerable damage in the Great Plains region. A somewhat similar disease attacks oats, rye, spelt, and barley. The black chaff appears in the spring in the form of yellow translucent stripes on the leaves and as black stripes or water-soaked areas on the culms and head. The kernels are infected from the dark sunken spots on the chaff, thus carrying over the disease in the seed.

The use of formaldehyde (p. 79), hot water (p. 79), or effective organic mercuric solution (p. 80), will prevent the spread through the seed but will not prevent other contamination.

BASAL GLUME ROT OF WHEAT

Basal glume rot (*Bacterium atrofaciens*) is confused at times with black chaff. It attacks mainly the chaff, forming a dark-brown or blackish area at the base of the glume, or chaff covering, usually the lower third. It also attacks the kernel, other portions of the head, and the leaves. In diseased grain the germ end varies in color from brown to black. No control is suggested other than resistant varieties, but seed treatment with liquid fungicides, including formaldehyde and organic mercuric solutions (p. 80), may prevent the spread of the disease through infected seed. The disease is, however, not likely to cause severe damage in California owing to the dry warm weather at the time of its greatest activity.

BACTERIAL BLIGHT OF BARLEY

Bacterial blight (*Bacterium translucens*) attacks all classes of barley and no immune varieties are known. It is widespread from the central states to the Pacific Coast. It attacks the leaves, causing water-soaked areas which later enlarge to blotches or irregular stripes, yellowish or brownish in color. An exudate appears on both leaf surfaces in the form of small gray drops which later dry and are readily detached. The exudate serves to distinguish bacterial blight from *Helminthosporium* leaf spot diseases. These drops teem with bacteria which live over in diseased tissue for two years or more. The disease is capable of causing severe losses.

There is a considerable range in varietal resistance in barleys of all groups, but no varieties have been found free from attack. Diseased seed should be avoided, but if it is used, seed treatment with liquid fungicides such as organic mercuric solutions (p. 80) or formaldehyde (p. 79) may prevent infection from the seed.

HALO BLIGHT OF OATS

Halo blight (*Bacterium coronafaciens*) is widespread on oats in the United States and annually causes losses in California. Sometimes wheat, barley, and rye are subject to slight attacks. The disease is readily distinguished by the oval blotches of various sizes which appear on the leaves and sheaths about heading time (fig. 41). The spots turn brown and dry out and die in the center, and are surrounded by pale yellowish-green halo-like margins. The tissues are not water-soaked and no drip, or exudate, occurs. The leaves die prematurely, causing a reduction in the number of filled florets and definitely shriveling the grain.

The disease may be carried by infected seed, straw, or chaff and may live over winter in seedling leaves, from which the attack may be transmitted by wind and rain. Seed treatment with formaldehyde reduces the severity of the attack but is not practical. Resistant varieties must be relied upon for control but no highly resistant varieties are now known.

BACTERIAL STRIPE OF OATS

Bacterial stripe or stripe blight (*Bacterium striafaciens*) of oats occurs in many of the central states and elsewhere in the United States. It is particularly severe in certain years in California. The spots or lesions first appear as water-soaked areas. When these spots coalesce and cover large portions of the leaves, long water-soaked stripes appear showing narrow yellow margins (figs. 42 and 43 *D*).

Fig. 41.—Halo blight of oats (*Bacterium coronafaciens*).

Fig. 42.—Stripe leaf blight of oats (*Bacterium striafaciens*). (After Elliott, U. S. Dept. Agr.)

During moist weather or early in the morning sticky bacterial exudate yellowish in color stands out in drops and many even coalesce and drip from the leaf. The exudate dries finally into thin white scales. This white scale and the absence of halo-like borders readily distinguishes it from halo blight of oats. The lesions form mainly on the leaves, but may occur on sheaths, culms, and glumes.

A wide difference in resistance occurs in varieties of oats. The commonly accepted oat of California, Kanota, is but slightly susceptible. Resistant varieties offer the only practical means of control.

BACTERIAL BLIGHT OF RYE

Bacterial blight of rye (*Bacterium translucens* var. *secalis*) differs from bacterial blight of barley (*Bacterium translucens*) mainly in that it is confined in its attacks to rye. It forms blotches which transform into water-soaked stripe-like lesions with a conspicuous exudate.

No resistant varieties are available, but the disease may be controlled by removing all shriveled kernels and follow by immersing the seed for ten minutes in 1:1000 copper sulfate solution, followed by a milk-of-lime dip. The presoak formaldehyde liquid treatment is also effective.

BACTERIAL WILT OF CORN

Bacterial wilt, or Stewart's disease (*Aplanobacter stewartii*), is principally a disease of sweet corn, but it may also attack other varieties. It is particularly severe in the eastern states. Early varieties of sweet corn may be reduced 50 per cent. All late varieties of corn escape.

The attacked plants die soon after becoming infected. They appear as though wilted from excessive drought. This wilting is most common when the plants are flowering, but it may be found at other stages. The water passages in the stalks become clogged with bacteria and if cut across exude a yellow viscous fluid. Death follows this plugging of the water passages.

The disease appears to be seed borne and is apparently not carried in the soil or in diseased tissue. By selecting disease-free ears or late-maturing varieties the disease may be avoided.

PURPLE LEAF SPOT OF MAIZE

Maize is usually found with purple blotches or spots on the leaf sheaths, as shown in figure 43 *A*. The spots have been found to arise from bacteria carried in the pollen sacks as they fall from the tassels.

These bacteria have not been positively identified. Entrance into the leaf is gained through the stomatal opening. As the infection comes late in the growth of the plant little damage results. Excessively dry weather reduces the disease.

Fig. 43.—*A*, Purple spot of oats (cause unknown). *B*, Crown rust of oats (*Puccinia coronata*) with red pustules (uredosori) unbroken. *C*, Crown rust of oats (*Puccinia coronata*). *D*, Stripe blight of oats (*Bacterium striafaciens*).

BACTERIAL STEM ROT

Bacterial stem rot (*Bacterium dissolvens*) is found in the warmer corn-growing areas and is known to attack many varieties; damage amounting to 30 per cent is recorded. Rotting of the roots and the

stalk to which they are attached follows infection. It is detected by brownish discolorations of the lower nodes, husks, leaf blades, and sheaths. The affected tissues ooze bacteria and death follows. There is no known remedy.

SORGHUM LEAF BLIGHT

Sorghum leaf blight (*Bacillus sorghi*) is common in all saccharine and grain sorghums, Sudan grass, and Johnson grass. It is readily detected by the appearance of irregular-shaped, elongated, red blotches which occur on the leaves and sheaths, especially on the inner surfaces next to the stalk. The affected parts turn black before they die. Roots and rootlets are also attacked and in severe cases the tops of the affected plants turn yellow.

As the disease is harbored in the soil, seed treatment is ineffective. Burning infected stalks and crop rotations with plants not subject to its attacks may avoid infection.

SORGHUM STRIPE

Bacterial stripe (*Bacterium andropogoni*) received its name from the long, narrow, red lesions which form long streaks on the leaf blades and sheaths. These lesions are similar in form in different varieties and vary in color from deep reddish-brown or purple to orange. The color is continuous throughout and not marginal, which distinguishes it from other sorghum spots.

It is found on broom corn and sweet and grain sorghums, but not on Sudan grass. Sweet sorghums are most susceptible, grass sorghums most resistant, and grain sorghums intermediate; degrees of variability occur within each group. The use of resistant varieties offers the only practical control.

PROSO BACTERIAL STRIPE

Proso, or broom corn millet, is attacked by a bacterial disease (*Bacterium panici*) which appears as brown water-soaked streaks in the leaves, sheaths and culms. Other millets are not affected. The lesions or streaks are narrow and vary from ¼ inch to several inches in length. An exudate forms into thin white scales. The disease is probably transmitted through the seed but may spread by means of rain.

Seed treatment with organic mercuric dips (p. 80), or formaldehyde (p. 79) offers the best method of control.

NEMATODE DISEASE OF WHEAT

Stem nematode, or eel worm (*Tylenchus tritici*) attacks wheat (fig. 44) and rye, but oats, barley, and certain grasses are much less susceptible. It enters the plant at the seedling stage, and lodging in the terminal bud passes up the stem, and finally hibernates in the seed,

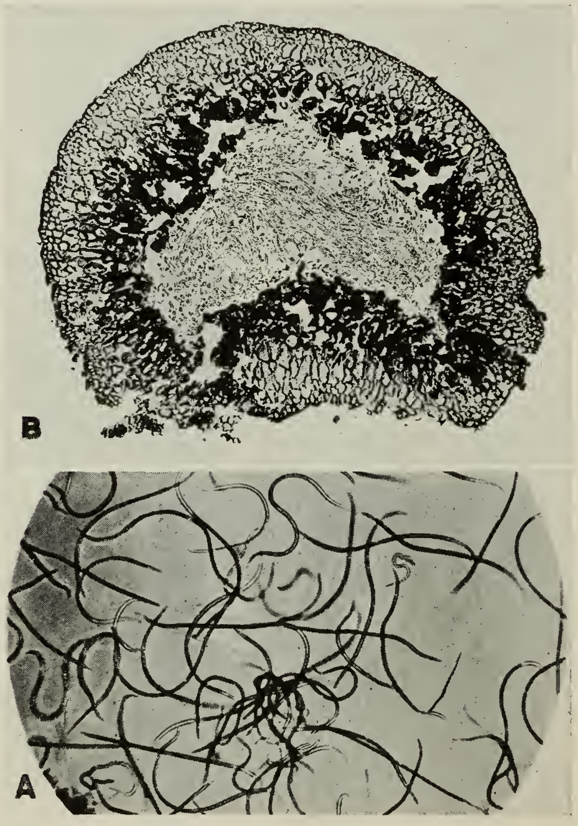

Fig. 44.—*A*, Nematode of wheat; *B*, wheat kernel showing mass of nematodes. (From U. S. Dept. Agr. Cereal Disease Investigations.)

which is converted into a dark tough gall, shorter and thicker than normal kernels and filled with thousands of eel worms. This gall closely resembles smut ball of the stinking smut of wheat. These eel worms remain alive for years if the wheat is stored dry. When the galls are sown the eel worms escape into the soil and thence to the young seedlings. Such seedlings are badly curled and twisted (fig. 45) and the mature plant is dwarfed.

This eel worm is found in several eastern and southern states and has appeared twice in California but the outbreaks were promptly suppressed. Great care should be taken to prevent it from entering the state in imported seed.

Strawberry nematode (*Tylenchus dipsaci*) also attacks the crowns and stems of some cereals, particularly wheat.

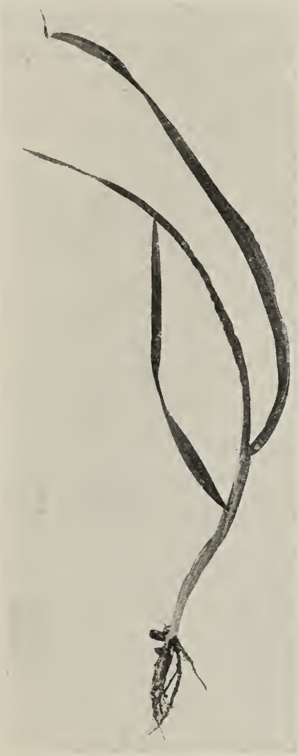

Fig. 45.—Wheat seedling showing the characteristic curling due to nematodes (*Tylenchus tritici*). From U. S. Dept. Agr. Cereal Disease Investigations.)

The stem-nematode disease is controlled by planting clean seed on clean land. Infested soil should be rotated to other noninfected crops for several years.

Nematode galls may be removed from infested seed by floating them off in a brine solution (p. 81). The galls should then be placed in boiling water to destroy the nematodes. Diseased seed can be effectively cleared of nematodes without removing the galls by immersing them in hot water at temperatures between 100.5° F to 104° F for 10 to 12 minutes.

NONPARASITIC DISEASES

Cereal crops may present diseased conditions which are not due to pathogenic organisms. The losses from such nonparasitic diseases may be as great as for many diseases caused by the organisms. Albinism, due to green color (chlorophyll) disturbance, dwarfness, barren stalks, and blast are some of these and cause serious crop losses. These troubles should be recognized and eliminated by breeding varieties free from the inherited deficiencies or by improving cultural conditions.

ALBINISM OR BLANCHING OF LEAVES

Albinism or whitening of leaves is found in maize, or sorghum, wheat, barley, oats, rice, rye, and grasses. It is not due to any disease organism nor to soil deficiencies but depends entirely upon inherited factors which carry susceptibility to this weakness. Those plants which remain entirely white soon die because they lack starch, which is formed by the green matter (chlorophyll) by means of the sunlight. Some plants retain some green matter and thus live to carry on this defect.

In barley the first two leaves of the infected seedling are green or striped green. The following leaves turn white. Whited leaves occur only when the temperature averages almost 45° F or below during the winter months. When the temperature rises above 65° F the leaves again become green. The same blanching in wheat seedlings has been repeatedly reported from many areas in the state for the past ten years. All known varieties of wheat and barley may be affected but great variation in percentage of attack occurs. Because albinism is a definitely inherited character, it can readily be eliminated from wheat and barley by selection of plants which do not inherit this defect. Many plants weakened by lack of green matter die in the seedling stages.

Other forms of albinism in which the leaves turn yellow or white and again revert to the green color are known in wheat and maize. Such blanched plants die before seed is produced, but the defect is carried by the hybrid or impure individuals.

Maize is also affected by several forms of albinism, white, yellow, and striped, that have no relation to temperature. Some forms produce pure white seedlings which soon die. The striped type appears later, on the leaves. The yellow type, when pure, dies. The reduction of yield and quality follows as with wheat and barley. Albinism in

maize and sorghum can be eradicated by selection and by selfing (hand pollinating with tassels from the same plant) pure lines until no albinism appears.

ROLLED OR CURLED LEAF

Rolled or curled leaf occurs in some wheat and barleys, including Hard Federation and White Federation wheats and Hero barley. The curled leaves do not interfere with the normal and healthy development of the plan. This character is a definitely inherited one and can be used in the identification of varieties.

Curled or rolled leaf should not be confused with curled leaf and distorted wheat and barley plants caused by downy mildew (p. 45 and fig. 29) or by wheat nematods (fig. 45).

DWARFNESS IN CEREALS

Dwarfness appears in wheat, barley, and oats, as well as in maize and sorghums. The small-grain plants do not develop normally and are shortened or rosetted until almost mature, when weak stalks arise, bearing heads which may or may not bear seed. Many seedlings die in the early stages. Dwarfness in maize does not appear in the rosette form but as a miniature stalk. These disturbances are inherited. They can therefore be eliminated by selecting plants free from this inheritance.

BLAST OF OATS

Blast in oats (fig. 46) is manifest in the premature death of the lateral branches of the heads (panicle) and the florets borne by them. The affected parts are decidedly blanched and appear as white threads. From a few to half the florets on a head may be affected. Both tame and wild oats are blasted where no relation to insects, fungus diseases, or hybrid origin can be detected. Abundance of plant foods and moisture in the soil may somewhat reduce blast but cannot markedly divert its occurrence.

Varietal resistance is practically constant. Several highly resistant varieties have been found, including Hatchet, Hutchison, Black C. I. 691, Fulghum, and Kanota. The latter appears to be the most resistant in California and solves the blast problem, since it is also the oat best adapted to our conditions.[5] In crosses between susceptible and resistant oats, resistance has been found to be dominant.

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[5] Mackie, W. W. Oat varieties in California. California Agr. Exp. Sta. Bul. 467:1–46. 1929.

HEAT CANKER OF FLAX

Heat canker is a nonparasitic disease which attacks flax plants when they are less than 4 inches high. The outer parts of the stem are attacked at the soil line, causing a canker which later results in the plants falling over. The attack occurs only during or immediately

Fig. 46.—*A*, Kanota with blast on first spikelet; *B*, Richland, blast very severe.

following very hot days, and is believed to be caused by excessive heat at the soil line affecting the plants when very succulent. Thicker seeding to shade the stems and early planting to avoid hot weather are suggested as preventive remedies.

STRAIGHTHEAD OF RICE

Straighthead is a physiologic disease caused by the decay of organic matter, which excludes air when water is applied, thus dis-

turbing the plant nutrition. The disease is detected by sterile or partly sterile heads which stand erect for want of filled kernels. The leaves are darker and stiffer than normal and the flower parts fail to develop properly. It appears on virgin soil and on land out of rice for a period. The remedy lies in draining the soil 5 or 6 weeks after the water is applied and leaving the soil to dry for 2 or 3 weeks to provide root aeration.

Straighthead caused by alkali or lack of water to cover the soil on high spots is a different form, but appears to have much the same effect on the rice plant except that the chaff of the rice head shows brown spots on one side. Keeping 6 inches or more of water over the soil during the whole growing period largely corrects straighthead due to alkali.

BARRENNESS OR STERILITY IN MAIZE

Barren stalks (not suckers) may be caused by soil infertility, late planting, low temperature, moisture deficiencies, and diseases. In maize heritable forms of barrenness commonly occur. These barren stalks may be taller and healthier than those of surrounding plants. Some bear no tassels. In many California fields barrenness is associated with excessive purple coloration in stalks and leaves. Barrenness due to heritable characters may be eradicated by breeding methods, but when due to other causes must be combatted according to environmental circumstances.

METHODS AND FORMULAS EMPLOYED IN THE CONTROL OF DISEASES OF GRAIN

The methods recommended for the control of the diseases of grain are given under the heads of (1) chemical applications to seed or plant, (2) application of heat to the seed, (3) cultural practices, and (4) planting disease-resistant varieties.

The chemical applications to the seed are made to destroy the diseases borne externally or internally by the seed. These chemicals include (*a*) liquid solutions, (*b*) gases or vapors, and (*c*) chemicals applied as dusts. All of these chemical methods have specific advantages and limitations. Bluestone or copper sulfate solution is very effective in destroying smut spores borne on the seed but it is very destructive to seed germs when the broken or scratched seed coat permits the entrance of the bluestone. Perfect or unbroken seed coats (fig. 2) resist successfully the entrance of bluestone under the recommended methods of seed treatment, but the processes of threshing and

cleaning the seed scratches and breaks the seed coats sufficiently to permit injurious amounts of the bluestone to attack the seed germ. This condition holds true for other chemicals which injure seed germs. The treatment of seed after the immersion in the bluestone solution, by giving it a bath in milk of lime, prevents some of the damage but the process is costly in labor and time. Presoaking the seed in water or washing immediately after dipping avoids seed injury but is likewise awkward and expensive.

Formaldehyde vapor was used to avoid the disadvantages of solutions, but this process proved to be difficult to apply and not always free from danger to seed.

Finally the discovery of copper carbonate dust[6] solved the problem of seed treatment for externally-borne disease spores. After this discovery tests with certain organic mercuric dusts demonstrated their efficiency also.

Disease germs borne inside of the grain seed, like barley stripe and loose smut, were not materially reduced by the ordinary bluestone and formaldehyde dips or copper carbonate dust. The use of hot water dips has long been practiced for control of such diseases but it is difficult for the farmer lacking the complicated equipment to hold the heat at the temperature required to kill the germs of the disease without injurying or destroying the seed germ. Certain of the mercuric compounds applied as liquids are effective in controlling internal seed-borne diseases without seed injury. A more limited number of these mercuric compounds applied as dusts are likewise effective in controlling these same diseases. Mercuric compounds, either as liquids or dusts, cause little or no seed injury. The ease of application and effectiveness of organic mercuric compounds makes them attractive but the prices are usually so high that they have not come into general use.

CULTURAL PRACTICES FOR DISEASE CONTROL

Crop rotation offers for many cereals diseases the only method to reduce or control the disease pending the discovery of resistant varieties. Foot-rot, which attacks wheat, barley, and rye, is one of this class. Flag smut of wheat may be eradicated from infested soil by rotations with barley or oats, which are not susceptible. Head smut of sorghum and maize can be controlled by no other known method. Scab, which attacks wheat, barley, rye, oats, and maize, may be

[6] Mackie, W. W., and Fred N. Briggs. Fungicidal dusts for the control of bunt. California Agr. Exp. Sta. Bul. **364**:533–567. 1923.

eliminated by crop rotation and by deep fall plowing to clean out and rot all material of host plants.

Irrigation of cereals susceptible to rust just before heading time favors rust attack.

HOT-WATER TREATMENT FOR SEED

The hot-water method is the most certain method of destroying the germs of diseases borne inside the seed, including loose smuts of wheat and barley, stripe disease of barley, sclerotium disease of rice, and similar diseases. Such diseases cannot be reached by the usual chemical solutions such as bluestone and formaldehyde. The hot-water method is especially recommended to prevent the introduction of new and foreign diseases on seed introduced from abroad. It is very tedious in application and subject to failure if the temperatures recommended are not carefully adhered to. Failure to hold the temperatures sufficiently high over the prescribed period may result in failure to destroy the disease germs, and if the temperature is too high the seed germs may be impaired or destroyed. There is usually a reduction in the vitality of the seed which should be taken care of by increasing the quantity of seed sown. Two methods are offered—the modified method and the single bath method.

Modified Method.—Soak the seed in half-filled bags, tied at the top. Soak 4 hours in cold water, dip in water about 120° Fahrenheit for a moment, then soak 10 minutes in water at 129° F for wheat and 126° F for barley.

Single-Bath Method.—Treat in sacks only half filled and tied at the top. Soak one hour and 35 minutes in water at 129° F for wheat and 126° F for barley.

For barley, rice, and oats, the time of application should be increased 30 per cent over the time given in the formulas. The seed should be dried to 15 per cent moisture if it is to be stored.

CHEMICAL TREATMENTS FOR SEED

Formaldehyde Solution.—Recommendation: Formaldehyde solution is recommended for the control of the smuts of oats. When used for bunt or covered smut of barley, it is not advisable to sow formaldehyde-treated seed in dry soil. Seed treated with formaldehyde should be sown immediately.[7]

[7] Mackie, W. W. Seed treatments for the prevention of cereal smuts. California Agr. Exp. Sta. Cir. 214:1–8. 1919. (Out of print.)

Formula: Place one pint of formaldehyde in 40 gallons of water. Presoak the seed for 10 minutes in water. Dip the presoaked seed for 15 minutes in the formaldehyde solution. Drain, dry, and sow in moist soil within 24 hours.

Formaldehyde Vapor (Haskell's Dry Method).—Recommendation: For oat smut.

Formula: To one pint of formaldehyde (formalin) add one pint of water. Heap the seed in a pile and shovel it over, spraying each shovelful with a hand sprayer. One quart is sufficient for 50 bushels of seed. After thus moistening the seed it should be confined with a canvas or blanket to confine the vapor. At the end of 5 hours the seed is ready to sow.

Bluestone Dip.—Recommendation: Used for bunt and covered smut of barley. Use only when copper carbonate or mercuric dusts are not available.

Formula: Presoak the seed in water for 5 to 15 minutes. Dip in bluestone solution (1 pound to 5 gallons of water) for 5 minutes. Drain thoroughly, dry and sow or store. Presoaking in water prevents some of the bluestone injury to seed germs.

Bluestone-Lime Dip.—Recommendation: To be used when bluestone is likely to cause seed germ injury.

Formula: Dissolve 1 pound of bluestone in 5 gallons of water. Dip the seed for 3 minutes; drain for 5 minutes; dip in the lime solution (1 pound of quicklime to 5 gallons of water) for 5 minutes. Drain and thoroughly dry. If not dried thoroughly the seed may heat and rot. The seed may be sown any time within two years without detrimental effect.

Organic Mercuric Solutions.—Recommendations: Solutions of proved organic mercuric compounds are used to control bunt, covered smut of barley, loose smut of barley and wheat, smuts of oats, stripe disease of barley, kernel and loose smut of sorghum, millet and proso smuts, and many other seed-borne diseases. Little or no seed injury follows the application of mercuric solutions.

Formula: Semesan, Uspulun and similar organic mercuric compounds are prepared as solutions by adding 1 ounce of the chemical to 3 gallons of water, and stirring until dissolved. Use containers of any material except aluminum. Immerse the seed for half an hour. Drain and dry the seed. After the third use of the solution replenish with a fresh supply.

Salt Solution for Ergot.—Recommendation: For the removal of ergots from wheat, barley, rice, rye, and rye grass, and eel worm galls in wheat.

Formula: Prepare a brine solution by dissolving 40 pounds of common salt in 25 gallons of water. Ergots, eel worm galls, and grains badly shrunken by scab, pink-root, or foot-rot, float readily and may be skimmed off. It is recommended that one washing in clean fresh water follow to remove injurious quantities of the salt. If seed diseases other than ergot are present, treatment for these diseases according to the recommendations for their control should follow.

Copper Carbonate Dust.

Recommendation: Copper carbonate dust has been found to be highly efficient, cheap, and reliable for the control of diseases arising from spores borne externally on the seed. These diseases include bunt or stinking smut of wheat and rye, flag smut of wheat, covered smut of barley, kernel smut of grain and sweet sorghums, Sudan grass, and proso. It is probably equally effective against smuts of millets. Grain weevils and beetle do not attack copper carbonate dusted seed and mice are repelled by the chemical.[8]

Method: Two grades of copper carbonate dust are found in the market. The more effective and expensive grade contains at least 50 per cent of metallic copper in the form of copper carbonate and copper hydrate in about equal proportions. It should be greenish in color and should pass through a 200-mesh screen. A reduced copper carbonate dust under the designation 'copper-carb' contains about 20 per cent metallic copper as carbonate and considerable gypsum. Two ounces per bushel for wheat and 3 ounces per bushel for barley of the dust containing the higher copper concentration, and 50 to 100 per cent more for the dust of lower copper content are recommended. Experience has demonstrated the greater effectiveness of the more concentrated dust. In areas where soil infestation from bunt is a factor the concentrated dust is much more efficient. However, in spring-sown fields and where only slight bunt infections occur the lower grade has frequently proved satisfactory.

Covered smut of barley is often not as well controlled by copper carbonate dust during the first season of its application, owing, no doubt, to the rough hull which protects the smut spores, but when the process is continued year after year without interruption the covered

[8] Mackie, W. W. Prevention of insect attack on stored grain. California Agr. Exp. Sta. Cir. 282:1–7. 1925.

smut of barley is controlled or entirely eradicated. The oat smuts are more difficult to control by copper carbonate dust than covered smut of barley.

Copper carbonate and other dusts are applied by means of barrel churn machines of the charge-and-discharge type, or by the continuous discharge type, consisting of revolving cylinders. Many home-made screw types are also successfully used. The result in any case must be a very thorough coating of the seed. This requires at best 3 minutes continuous mixing. Many very efficient machines are available in the market.

A dust mask or wet sponge should be worn over the mouth and nose to prevent inhaling the poisonous dust.

Organic Mercuric Dusts.

Many combinations of these dusts have been offered in the market, but at present the most effective appears to be Ceresan. Merko, Semesan, and Semesan Jr. are also used effectively.

Recommendations: The effective organic mercuric dusts are as efficient as copper carbonate dust for the control of the seed-borne diseases for which this dust is recommended. These dusts are applied to the seed in the same manner as copper carbonate dust. In addition, certain diseases borne internally by the seed are controlled by Ceresan and similar dusts. Ceresan is recommended for the control of barley stripe, and scab and *Fusarium* in grain. All these mercuric dusts are used for diseased seed corn.

DUSTS APPLIED TO PLANTS IN FIELD

Obviously the application of liquid chemical sprays to prevent or check fungus diseases of growing cereals is not practical. Sulfur dust for rust control has been successfully applied by aeroplanes to wheat fields (fig. 16). Three applications applied at the rate of 50 to 150 pounds per acre at intervals of 5 to 7 days, beginning at the flowering period, have been markedly successful and offer promise for the large wheat fields in the Tulare Lake and Sutter Basin regions. Experimental grain plots may be successfully protected from rust and powdery mildew by dusting with flowers of sulfur.

DISEASE PREVENTION BY RESISTANT VARIETIES

Seed treatment and cultural practices have been found effective for the control or prevention of many cereal diseases, but these practices must be repeated for each crop. The permanent prevention of cereal diseases rests upon resistant varieties. The permanence of this method depends upon the fixity of the cereal variety and also upon the stability of the disease organism. The cereal variety may change in its degree of resistance because of field crossing or mutations. The fungus organism which causes the disease may likewise change by the same methods, thereby creating new disease forms which may attack varieties resistant to the previously existing forms. However, self-fertilized varieties like wheat, rye, oats, barley, and rice are not likely to change. Neither do diseases appear to change radically or frequently. These conditions make possible the scientific breeding of new disease-resistant varieties which will be effective for a long period.

Wherever possible those varieties known to be resistant to a given disease have been listed when recommending measures for the control of each disease. In many instances the varieties may not be adapted to certain regions or may be poor yielders or poor in quality. They may, however, be used in breeding new disease-resistant varieties. By following this program it is believed that it will be possible to secure varieties resistant to all cereal diseases, if the effort is continued and diligently prosecuted. The cost of breeding disease-resistant varieties of high quality and yield is the price for securing high yields and freedom from losses by diseases.

INDEX OF DISEASES ACCORDING TO HOST

15*m*-4,'31